GEOTECHNICAL INVESTIGATION
SURFACE WATER TRANSMISSION PROGRAM
84-INCH WATER LINE
INTERCONNECT AT EAST WATER
PURIFICATION PLANT (EWPP)
WBS NO. S-000902-0132-3
HOUSTON, TEXAS

REPORT NO. 1140193701

Reported to:

LOCKWOOD ANDREWS & NEWNAM, INC.

Houston, Texas

Submitted by:

GEOTEST ENGINEERING, INC.

Houston, Texas

Key Map Nos. 496 U

GEOTEST ENGINEERING, INC.

Geotechnical Engineers & Materials Testing

5600 Bintliff Drive   Houston, Texas 77036   Telephone: (713) 266-0588
Fax: (713) 266-2977

Report No. 1140193701
December 3, 2013

Mr. Will Wilshire, P.E.
Lockwood Andrews & Newnam, Inc.
2925 Briarpark Drive, Suite 400
Houston, Texas 77042

Reference: **Geotechnical Investigation**
Surface Water Transmission Program
84-inch Water Line Interconnect at
East Water Purification Plant (EWPP)
WBS No. S-000902-0132-3
Houston, Texas

Dear Mr. Wilshire:

Presented herein is the final geotechnical investigation report for the above referenced project. Preliminary boring logs were submitted to LAN on May 3, 2013. A draft report was submitted to you on June 18, 2013. This final report supersedes all previously submitted reports, transmittals, etc. for the referenced project. This study was authorized by Task Order 972/2 on March 15, 2013 by accepting our Proposal No. 1140326599, dated February 1, 2013.

We appreciate this opportunity to be of service to you. Please call on us when we can be of further assistance to you.

Very truly yours,
GEOTEST ENGINEERING, INC.
TBPE Registration No. F-410

Naresh Kolli, P.E.
Assistant Project Manager

STATE OF TEXAS
12/3/13
NARESH KOLLI
110928
LICENSED
PROFESSIONAL ENGINEER

Mohan Ballagere, P.E.
Vice President

STATE OF TEXAS
12/3/13
MOHAN BALLAGERE
87622
LICENSED
PROFESSIONAL ENGINEER

MB/NK/ego
Copies Submitted: (2+1-pdf)
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EXECUTIVE SUMMARY

A geotechnical investigation was conducted in connection with the design and construction of 84-inch Water Line Interconnect from CWA Building at Plant 3 to New PRS (Pressure Regulating Station) at Plant 1 and 2 at East Water Purification Plant. The proposed construction of water line is generally by open cut method except at the crossings of Hunting Bayou and Private Pipelines, where tunneling is proposed.

This investigation included drilling and sampling four (4) soil borings to depths ranging from 25 to 50 feet, performing laboratory tests on soil samples recovered from the borings, performing engineering analyses and preparing a geotechnical report.

The principal findings and conclusions developed from this investigation are summarized below:

- Based on review of Harris-Galveston coastal subsidence district maps, it was noted that subsidence in the Houston area has substantially decreased in recent years. During 1906 through 2000, subsidence in the project area appears to have been between 7 and 8 feet. During 1978 through 2000, subsidence in the project area appears to have been between 0.5 and 1 feet. During 1995 through 2010, subsidence in the project area appears to have been between 0 and 0.25 feet.

- Based on the review of the available information, the nearest known surface fault is of faults associated with Clinton Salt Dome which is approximately 1,000 feet north of the project alignment. The available information consisted of U. S. Geological Survey maps, open file reports, and information contained in our files relating to geologic faults in the area.

- The subsurface conditions for proposed 84-inch Water Line Interconnect at EWPP are summarized below:

As revealed by boring logs GWL-1 through GWL-4, the subsurface soil below the existing grade consists of medium stiff to hard brown, gray, yellowish brown and reddish brown Fat Clay, Lean Clay and Sandy Lean Clay to depths of 25 feet, the explored depths in borings GWL-1 and GWL-2 and to depths of 34 and 36 feet in borings GWL-3 and GWL-4. In borings GWL-3 and GWL-4, the clays are underlain by dense to very dense gray and reddish brown Sandy Silt and Silty Sand to explored depths of 50 feet. A stratum of medium dense reddish brown silty sand and loose gray sandy silt was encountered between the depths of 10 and 14 feet in borings GWL-2 and GWL-3 respectively. In borings GWL-3 and GWL-4, fill material consisting of medium stiff to very stiff brown, yellowish brown, gray and reddish brown Sandy Lean Clay and Fat Clay w/grass roots, calcareous and ferrous nodules was encountered to a depth of 6 and 10 feet below the existing grade.

- The groundwater was encountered at depths ranging from 10 feet to 23 feet in all the borings GWL-1 through GWL-4 during drilling. The water level measured 15 to 20 minutes after water was first encountered is at depths ranging from 5.3 to 21 feet in these borings. The groundwater as observed on May 16, 2013 in Piezometer GWL-3P is at depth of 3.5 feet.

- All excavations and trenching operations should be in accordance with OSHA standards.

- Bedding and backfill for the 84-inch Water Line Interconnect should be in accordance with the City of Houston Standard Specification Section 02511 “Water Lines” and Drawing No. 02317-04.

- Geotechnical parameters for design of restrained joints, tunneling and structures are provided in Section 5.0 of this report.

1.0 INTRODUCTION

1.1 General

Lockwood Andrews & Newnam, Inc. (LAN) was selected by City of Houston to provide engineering design construction program management services in support of Surface Water Transmission Program (SWTP). LAN then selected Geotest Engineering, Inc. to provide geotechnical engineering services related to the design and construction of 84-inch Water Line Interconnect.

1.2 Location and Description of the Project

A geotechnical investigation was conducted in connection with the design and construction of 84-inch Water Line Interconnect from CWA Building at Plant 3 to New PRS (Pressure Regulating Station) at Plant 1 and 2 at East Water Purification Plant. The proposed construction of water line is generally by open cut method except at the crossings of Hunting Bayou and Private Pipelines, where tunneling is proposed.

The vicinity map is shown on Figure 1.

1.3 Scope of Work

The purposes of this investigation were to determine the subsurface conditions and to develop geotechnical recommendations for the design and construction of the proposed 84-inch Water Line Interconnect from CWA Building at Plant 3 to new PRS at Plant 1 and 2 at EWPP. The scope of this investigation was based on the information furnished by LAN and consisted of the following tasks.

- Drilling and sampling (intermittent and continuous) of four (4) borings and installing one (1) piezometer in existing boring. The continuous sampling was performed from 0 to 20 feet and in the tunneling zone. The tunneling zone includes one bore diameter or minimum 6 feet above the pipe crown to one bore diameter or minimum 6 feet below the pipe invert. The intermittent sampling was performed at 5-foot intervals in the remainder depths of borings.

- Performing appropriate laboratory tests on selected samples to develop engineering properties of the soil.

- Performing engineering analyses to develop geotechnical recommendations for the design and construction of the 84-inch Water Line Interconnect.

- Preparing a geotechnical report in accordance with City of Houston Guidelines and the SWTP Manual. The report includes all field data, laboratory test data and geotechnical recommendations.

2.0 SUBSURFACE INVESTIGATION PROGRAM

2.1 Geotechnical Borings

Subsurface conditions were explored by drilling and sampling four (4) soil borings, designated as GWL-1 through GWL-4, to depths ranging from 25 to 50 feet. The borings were marked in the field by Geotest representative based on the drawings provided to us by LAN. The borings were drilled with a truck mounted drilling rig. The approximate locations of all these borings are shown on Figure 2, Plan of Borings. The survey information (Northing and Easting coordinates and ground surface elevation) of the completed borings were provided to us by LAN. A summary of subsurface investigation program is provided in Table 1.

Samples were obtained continuously to a 20-foot depth and at 5-foot intervals thereafter in borings GWL-1 and GWL-2. In borings GWL-3 and GWL-4 drilled at tunnel location at Hunting Bayou crossing, samples were obtained continuously to a 41-foot depth and at 5-foot intervals in the remainder depth of borings. In general, samples of cohesive soils were obtained with a 3-inch thin-walled tube sampler in general accordance with ASTM Method D 1587 and cohesionless soils were sampled with a 2-inch split-barrel sampler in accordance with ASTM Method D1586. Each sample was removed from the sampler in the field, carefully examined, and then logged by an experienced soils technician. Suitable portions of each sample were sealed and packaged for transportation to Geotest's laboratory. The shear strength of cohesive soil samples was estimated using a pocket penetrometer in the field. Driving resistances for the split-barrel samples were recorded as "Blows per Foot" on the boring logs. All borings were grouted with cement bentonite grout after completion of drilling and obtaining water level measurements with the exception of boring GWL-3 which was converted to piezometer.

Detailed descriptions of the soils encountered in the borings are given on the boring logs presented on Figures A-1 through A-4 in Appendix A. A key to "Symbols and Terms used on Boring Logs" is given on Figure A-5 in Appendix A.

2.2 Piezometer Installation

During the field investigation, a piezometer was installed in the open bore hole of boring GWL-3. The location of the piezometer, designated as GWL-3P, is shown on Figure 2. Piezometer installation record showing details of the construction of piezometer is provided on Figure C-1 in Appendix C.

Piezometer was abandoned in place after taking the final water level measurements. The piezometer abandonment reports are presented on Figure C-2 in Appendix C.

3.0 LABORATORY TESTING PROGRAM

The laboratory testing program was designed to evaluate the pertinent physical properties and shear strength characteristics of the subsurface soils. Classification tests were performed on selected samples to aid in soil classification. All the tests were performed in accordance with appropriate ASTM procedures.

Undrained shear strengths of selected cohesive samples were measured by unconsolidated undrained (UU) triaxial compression (ASTM D2850) tests. The results of UU triaxial compression tests are plotted on the boring logs as solid squares. The shear strength of cohesive samples was measured in the field with a calibrated hand pocket penetrometer and also in the laboratory with a Torvane. The shear strength values obtained from the penetrometer and Torvane are plotted on the boring logs as open circles and triangles, respectively.

Measurements of moisture content and dry unit weight were taken for each UU triaxial compression test sample. Moisture content measurements (ASTM D2216) were also made on other samples to define the moisture profile at each boring location. The liquid and plastic limit tests (ASTM D4318) were performed on appropriate samples. Sieve analysis (ASTM D422) and percent passing No. 200 sieve (ASTM D1140) tests were performed on selected samples. The results of all tests are plotted or summarized on the boring logs. The summary of laboratory test results is also presented in a tabular form on Figures B-1 through B-4 in Appendix B. Grain size distribution curves are presented on Figures B-5 and B-6 in Appendix B.

4.0 SUBSURFACE AND SITE CONDITIONS

4.1 Geology of the Coastal Plain

The geology of Harris County is characterized by two formations. The Beaumont formation is located in the southeastern portion of the county and the Lissie formation is located in the northwest. Both the Beaumont and the Lissie formations are part of the fluvial and marine coastal complex resulting from the glacial cycles within the Pleistocene/Holocene epoch. Seaward, the lithologies are primarily dominated by clays, often interspersed with coarser sediments, primarily silts and sands. Northern portions of Harris County are under the influence of the drainage systems established by rivers such as the Brazos and the San Jacinto. The lithologic pattern generally includes silt, sand and clay with minor amounts of calcareous nodules and iron oxide. Various mineral impregnations are associated with the lithologies. Primary among these are the ferruginous-iron-based and calcareous minerals, which include calcium carbonate. These minerals impart an acidic or alkaline characteristic to soils.

Based on the Texas, Geologic Atlas of Texas - Houston Sheet (Bureau of Economic Geology, University of Texas, 1982) the location of the project alignment is located on the Beaumont Formation. The clays and sands of this formation are overconsolidated as a result of desiccation or frequent raising and lowering of the sea level and subsequently the groundwater table. Consequently, clays of this formation have moderate to high shear strength and relatively low compressibility. Sands of the Beaumont Formation are typically very fine and often silty. Further, there is occasional evidence in the Houston area of the occurrence of cemented material (sandstone and siltstone) deposits within the Beaumont Formation.

There are two principal geologic hazards that are characteristic of these younger depositionals formation of the Pleistocene Epoch. The first is land surface subsidence which is the result of heavy pumpage of water from the underlying aquifers and to a lesser extent withdrawal of oil and gas. Since creation of the Harris-Galveston Coastal Subsidence District in the mid 1970s to regulate pumpage of groundwater, subsidence has been on the decline. Subsidence is not expected to impact this project. The second hazard is the presence of active growth faults and faults resulting from piercement of the formations by mobile salt masses. These faults are nontectonic and, in fact, Houston is located in a Seismic Zone of 0 according to the Uniform Building Code.

4.2 Natural Hazards

4.2.1 Subsidence - Land surface subsidence, related to groundwater pumpage and to a lessor extent, the withdrawal of oil and gas, has probably occurred in the Harris County area since the early settlers began to drill wells. During the period of 1906 to 2000, subsidence in the project area appears to have been between 7 and 8 feet.

In 1976, the State Legislature created the Harris-Galveston Subsidence District to regulate the pumpage of groundwater. Since creation of the district, the overall rate of subsidence in Harris County has been substantially reduced. Subsidence in the project area during the period of 1978 to 2000 appears to be between 0.5 and 1 feet. Subsidence in the project area during the period of 1995 to 2010 appears to be between 0 and 0.25 feet.

4.2.2 Geologic Faults in Vicinity of Site - A review of information in the Geotest library relating to known surface and subsurface geologic faults, in the general area of the project alignment, was undertaken. The available information consisted of U. S. Geological Survey maps, open file reports, and information contained in our files relating to geologic faults in the area.

Based on the review of the available information, the nearest known surface fault is of faults associated with Clinton Salt Dome which is approximately 1,000 feet north of the project alignment.

4.3 Site Stratigraphy and Geotechnical Characterization

Based on the subsurface soils encountered in the discrete boreholes drilled, one (1) boring log profile was developed and is presented on Figure 3. To the left of each boring shown on the profile is an indication of the consistency or density of each stratum. More than one consistency or density for an individual stratum indicates that the consistency or density is different at different depths within the stratum. For cohesive soils, consistency is related to the undrained shear strength of the soil. For granular soils, the relative density is related to the standard penetration resistance of the soil. The symbols and abbreviations used on boring log profiles are given on Figure 4. To the right of each boring shown on the profile is the overall classification of the soil contained within each stratum. The classification is based on ASTM D2487.

The subsurface conditions for proposed 84-inch Water Line Interconnect at EWPP are summarized below:

As revealed by boring logs GWL-1 through GWL-4, the subsurface soil below the existing grade consists of medium stiff to hard brown, gray, yellowish brown and reddish brown Fat Clay, Lean Clay and Sandy Lean Clay to depths of 25 feet, the explored depths in borings GWL-1 and GWL-2 and to depths of 34 and 36 feet in boring GWL-3 and GWL-4. In borings GWL-3 and GWL-4, the clays are underlain by dense to very dense gray and reddish brown Sandy Silt and Silty Sand to explored depths of 50 feet. A stratum of medium dense reddish brown silty sand and loose gray sandy silt was encountered between the depths of 10 and 14 feet in borings GWL-2 and GWL-3 respectively. In borings GWL-3 and GWL-4, fill material consisting of medium stiff to very stiff brown, yellowish brown, gray and reddish brown Sandy Lean Clay and Fat Clay w/grass roots, calcareous and ferrous nodules was encountered to a depth of 6 and 10 feet below the existing grade.

The Sandy Lean Clay and Lean Clay is of low to high plasticity with a liquid limit ranging from 25 to 44 and plasticity indices ranging from 9 to 24. The Fat Clay is of high to very high plasticity with liquid limits ranging from 50 to 87 and plasticity indices ranging from 29 to 56.

The percent fines (percent passing No. 200 sieve) of Silty Sand is about 41 percent and the percent fines of Sandy Silt ranges from 58 to 69 percent. The percent fines of Sandy Lean Clay ranges from 54 to 69 percent. The percent fines of Lean Clay and Fat Clay ranges from 86 to 99 percent.

4.4 Groundwater

The groundwater was encountered at depths ranging from 10 feet to 23 feet in all the borings GWL-1 through GWL-4 during drilling. The water level measured 15 to 20 minutes after water was first encountered is at depths ranging from 5.3 to 21 feet in these borings. The groundwater as observed on May 16, 2013 in Piezometer GWL-3P is at depth of 3.5 feet. However, various environmental and man-made factors such as amount of precipitation can substantially influence groundwater level.

4.5 Environmental Issues

Nothing was observed or detected during our investigation to suggest any environmental concerns.

5.0 GEOTECHNICAL ENGINEERING RECOMMENDATIONS

The project consists of the design and construction of 84-inch Water Line Interconnect from CWA Building at Plant 3 to New PRS (Pressure Regulating Station) at Plant 1 and 2 at East Water Purification Plant. The proposed construction of water line is generally by open cut method except at the crossings of Hunting Bayou and Private Pipelines, where tunneling is proposed.

5.1 Trench Excavation

5.1.1 Geotechnical Parameters. Based on the soil conditions revealed by the borings, geotechnical parameters were developed for the design of the 84-inch Water Line Interconnect at EWPP. The geotechnical design parameters are provided in Table 2. For design, the groundwater level should be assumed to exist at the ground surface, since these conditions may exist after a heavy rain or flooding.

5.1.2 Excavation Stability. It is understood that the proposed construction of 84-inch Water Line Interconnect is generally by open cut method except at the crossings of Hunting Bayou and Private Pipelines, where tunneling is proposed. The open excavation may be shored, laid back to a stable slope or supported by some other equivalent means used to provide safety for workers and adjacent structures. The excavating operations should be in accordance with OSHA Standards, OSHA 2207, Subpart P, latest revision and the City of Houston requirements.

- Excavation Shallower Than 5 Feet – Excavations that are less than 5 feet (critical height) deep should be appropriately protected when any indication of hazardous ground movement is anticipated.

- Excavations Deeper Than 5 Feet - Excavations that are deeper than 5 feet should be sloped, shored, sheeted, braced or laid back to a stable slope or supported by some other equivalent means or protection such that workers are not exposed to moving ground or cave-ins. The slopes and shoring should be in accordance with the excavation safety requirements per OSHA Standards. The following items provide design criteria for excavation stability.

(i) OSHA's Soil Type. Based on the soil conditions revealed by the borings and the design groundwater level, OSHA's soil type "C" should be used for the determination of allowable maximum slope and/or the design of a shoring system. For shoring deeper than 20 feet, an engineering evaluation is required.

(ii) Maximum Side-slopes. Based upon the results from the field and laboratory investigations of borings GWL-1 through GWL-4, it is our opinion that, temporary open-trench excavations with depths greater than 5-ft and less than about 20-ft, in general, may be made with slopes of 1.5(H):1(V) where sandy lean clay, lean clays and fat clays are encountered. When there are signs of distress or if water seepage is evident, the entire excavation must have side-slopes of 2(H):1(V). Trenches greater than 20 feet in depth must be designed by a professional engineer.

The Contractor designated "Competent Person" should review our recommendations and determine the appropriate safe slopes on the job site at the time of construction.

(iii) Excavation Support Earth Pressure. Based on the subsurface conditions indicated by this investigation and laboratory testing results, excavation support earth pressure diagrams were developed and are presented on Figures 5.1 through 5.3 (Reference 1). These pressure diagrams can be used for the design of temporary excavation bracing. For a trench box, a lateral earth pressure resulting from an equivalent fluid with a unit weight of 92 pcf is recommended. The above value of equivalent fluid pressure is based upon an assumption that the groundwater level is near the ground surface, since these conditions may exist after a heavy rain or flooding. Effect of surcharge loads at the ground surface should be added to the computed lateral earth pressures. A surcharge load, q, will typically result in a lateral load equal to 0.5 q. The example calculations of bracing pressures are presented in Appendix D.

(iv) Excavation Bottom Stability. In braced cuts, if tight sheeting is terminated at the base of the cut, the bottom of the excavation can become unstable under a certain conditions. This condition is governed by the shear strength of the soils and by the differential hydrostatic head between the groundwater level within the retained soils and the groundwater level at the interior of the trench excavation. For cuts in cohesive soils as encountered in the borings (Sandy Lean Clay, Lean Clay and Fat Clay), for excavation depths of 15 to 40 feet, stability of the bottom can be evaluated in accordance with the procedure outlined on Figure 6 (Reference 2). **However due to cohesionless soils (Silty Sand and Sandy Silt) encountered at borings GWL-2 (between depths of 10 and 13 feet), GWL-3 (between depths of 10 and 13 feet and 36 and 50 feet) and GWL-4 (between depths of 34 and 50 feet), the excavation should be done after dewatering to avoid bottom stability problems.**

5.1.3 Access Shaft for Tunneling. The access shafts proposed for the trenchless method should be constructed per City of Houston Standard Specifications, Section 02400 (tunnel shafts). The access shaft may be constructed by retained excavations or can be installed by sunken caisson. These methods are described below:

- Retained Excavation. Retained excavations generally require less ground surface area than open-cut excavation with laid back slopes. The retention system can consist of driven sheetpile, liner plates, solider pile/lagging, driven planking, or ring beams and timber lagging. The items pertaining to design criteria for retained excavation stability should be in accordance with guidelines as outlined in section 5.1.2.

- Sunken Caisson Installation. The caisson procedure eliminates the need for a temporary retention system. Caisson units can, however, experience problems with alignment and termination at the proper design depth. Stability considerations of the excavation bottom are similar to those for retained excavation techniques.

5.2 Excavation Dewatering

Excavations for the proposed 84-inch Water Line Interconnect will encounter groundwater seepage to varying degrees depending upon the groundwater conditions at the time of construction and the location and depth of the trench or excavation.

Based on the soil conditions identified in the borings for the proposed 84-inch Water Line Interconnect, the excavations (based on excavation depths of 15 to 40 feet) will be in cohesive soils in boring GWL-1, cohesive with intermittent cohesionless or cohesive underlain by cohesionless soils in borings GWL-2, GWL-3 and GWL-4.

In cohesive soil, groundwater may be managed by collection in trench bottom sumps for pumped disposal.

In cohesionless soil, dewatering such as well point system upto excavation depth of 15 feet and deep wells with submersible pumps for excavation greater than 15 feet deep will be required to lower the groundwater level to at least 5 feet below the level of excavation. The well point system or deep wells should be pumping well ahead of the time excavation starts so that a steady state condition (at least 5 feet below the proposed excavation bottom) is achieved.

It is recommended that the actual groundwater conditions be verified at the time of construction and that the groundwater control be performed in general accordance with the City of Houston Standard Specifications, Section 01578.

5.3 Vehicular Traffic and Railroad Loads

The proposed construction of water line is generally installed by open cut method except at the crossings of Hunting Bayou crossing and private pipelines, where tunneling is proposed. The proposed 84-inch Water Line Interconnect will be steel pipe. The vertical load on underground conduit will be based on type of installation and type of pipe i.e. rigid or flexible.

5.3.1 Vertical Earth Pressure on Ditch Conduit. The vertical load on an underground conduit depends principally on the weight of the prism of soil directly above it. In the case of a ditch conduit, the backfilling material has a tendency to consolidate and settle downward. This action plus the settlement of the conduit into its soil foundation causes the prism of soil within the ditch and above the pipe to move downward relative to the undisturbed soil at the sides. This relative movement along the sides of the ditch mobilizes certain shearing stresses or friction forces which act upward in direction and which, in association with horizontal forces, create an arch action that partially supports the soil backfill. The difference between the weight of the backfill and these upward shearing stresses is the load that must be supported by the conduit at the bottom of the ditch.

- Flexible Pipe Conduit. Under soil load, a flexible pipe tends to deflect, thereby developing passive soil support at the sides of the pipe. At the same time, the ring deflection relieves the pipe of the major portion of the vertical soil load which is picked up by the surrounding soil in an arching action over the pipe. However, a convenient design for a flexible pipe (e.g., steel pipe) would be the prism load which is the weight of a vertical prism of soil over the pipe. The prism load is given by the following equation:

$$P_c = \gamma H$$

or $$W_c = \gamma H B_c \text{ (Reference 3)}$$

in which

P_c = pressure due to weight of soil, psf

W_c = vertical load per unit length of conduit, lb/linear ft

γ = wet unit weight of backfill material, pcf (recommended 120 pcf)

H = height of fill above top of pipe (conduit), feet

B_c = outside diameter of pipe, feet

- Rigid Pipe Conduit. For the case of a rigid conduit with relatively compressible side fills, the load on the conduit will be:

$$W_d = C_d \, \gamma \, B_d^2 \quad \text{(Reference 4)}$$

where W_d = fill load in lbs/linear ft. of conduit

C_d = trench load coefficient

γ = wet unit weight of backfill material, pcf (recommended 120 pcf)

B_d = width of trench at or slight below the level of the top of the conduit, in feet

The trench load coefficient C_d is a function of the trench depth to width ratio and the frictional characteristics of the backfill material and sides of the trench. C_d can be determined using the following equation:

$$C_d = \frac{1 - e^{-2K\mu'\left(\frac{H}{B_d}\right)}}{2K\mu'} \quad \text{(Reference 4)}$$

where K = tan (45°- ϕ'/2) = Rankine's ratio of active lateral unit pressure to vertical unit pressure, with ϕ' = friction angle between backfill and soil

μ' = tan ϕ' = coefficient of friction between fill material and sides of trench

H = height of fill above top of pipe, in feet

B_d = width of trench at top of pipe in feet

For design, $K\mu'$ = 0.150 may be used for saturated top soil.

5.3.2 Load on Conduit Due to Traffic Loads. In addition to the vertical earth pressure or overburden, underground conduits are also subject to live loads, such as wheel loads applied at the surface of the backfill and transmitted through the soil to the underground structure. The live load on the conduit due to traffic loads can be calculated using the following equation.

$$W_L = \frac{W_T}{L_e} \quad \text{(Reference 4)}$$

where W_L = live load on pipe, in pounds per linear feet

W_T = total live load in pounds

L_e = effective supporting length of pipe, in feet

L_e is determined by the following equation:

$$L_e = L + 1.75\,(3B_c/4) \quad \text{(Reference 4)}$$

where L = length of A_{LL}, parallel to longitudinal axis of pipe, in feet

B_c = outside diameter of pipe, in feet

and W_T is the total live load acting on pipe is given by:

$$W_T = w_L\, L\, S_L \quad \text{(Reference 4)}$$

where w_L = average pressure intensity in pounds per square foot given by

$$w_L = \frac{WH(I_f)}{A_{LL}} \quad \text{(Reference 4)}$$

WH = total applied surface wheel loads, in pounds

A_{LL} = distributed live load area in square feet

I_f = Impact factor (use 1.0 as height of cover is 3 feet or greater)

S_L = outside horizontal span of pipe or width of A_{LL}, transverse to longitudinal axis of pipe, whichever is less, in feet

Depending on height of cover and wheel load, A_{LL}, distributed live load area can be computed from the following table (Reference 4):

Height of Cover *(ft)*	Wheel Load *(lb)*	A_{LL}, Distributed Load Area *(ft x ft)*	
H<1.33	16,000	(0.83 + 1.75H)	(1.67 + 1.75H)
1.33 < H < 4.10	32,000	(0.83 + 1.75H)	(5.67 + 1.75H)
4.10 < H	48,000	(4.83 + 1.75H)	(5.67 + 1.75H)

Loads on the pipe due to vehicular traffic crossing should also be considered. A graph providing calculated vertical stress on pipe due to traffic loads is given on Figure 7. The load, whichever gives higher value due to traffic, should be considered for design.

5.3.3 Pipe Bedding and Backfill. It is recommended that the City of Houston Standard Specification 02511 “Water Lines” and Standards Drawing No.02317-04 should be followed for bedding and backfill.

5.3.4 Shaft Backfill. The excavated shafts should be backfilled per City of Houston Standard Specifications, Section 02400, “Tunnel Shafts,” Subsection 3.04.

5.3.5 Influence of Open Cut Excavation on Adjacent Structures. Based on the information available to us, the open cut excavation for the proposed 84-inch Water Line Interconnect are generally through the easement and there are no immediate building structures along the proposed excavations. However, underground utilities may be adjacent to the excavations and should be properly protected during excavations and monitored during and after the excavation and dewatering.

5.4 Pressures on Primary and Permanent Liners

The proposed 84-inch Water Line Interconnect crossing Hunting Bayou and private pipelines will be installed by bore and jack method of tunneling.

5.4.1 Geotechnical Parameters for Trenchless Installation. Based on the soil conditions revealed by the borings (GWL-3 and GWL-4) and laboratory test data, geotechnical design parameters were developed for cohesive soils and cohesionless soils. The geotechnical design parameters are provided in Tables 3.1 and 3.2. The cohesive soils include Fat Clay, Lean Clay and Sandy Lean Clay, and the cohesionless soils include silty sand and sandy silt. For design conditions, the groundwater levels should be assumed to exist at the ground surface, since this condition may exist after a heavy rain or flooding.

5.4.2 Earth Pressure on Tunnel. The earth pressures on the tunnel liner should be determined from Figure 8 (Reference 5). Equations to calculate the tunnel liner loads are also shown in Figure 8. For tunnel crossing under the major streets, the stress due to traffic loads should be constructed. The relationship between the depths of pipe and the vertical stress on the pipe due to traffic live loads is provided on Figure 7.

5.4.3 Carrier Pipe Design Parameters. Carrier pipe must be sufficiently strong to withstand anticipated long-term ground loads and must not be subject to deterioration by substance either in the ground or in the tunnel. The carrier pipe design should include consideration of not only the loads applied to the pipe but also factors other than soil loading. These factors could include minimum structural code requirements, loading from pipe jacking operations and other construction loads. The drained geotechnical design parameters given in Table 3 should be used in analyzing the soil structure intersection of the carrier pipe.

5.5 Piping System Thrust Restraint

Unbalanced thrust forces will occur at any point in the pipe where the direction or cross sectional area of the flow changes. The force diagram shown on Figure 9 (Reference 4) illustrates the thrust force generated by flow at a bend in the pipe. The equations for computing this thrust force are also given on this figure. The thrust force will often require more resistance or support than is available just from the pipe bearing against the backfill. In order to prevent intolerable movement and overstressing of the pipe, suitable buttressing should be provided.

Based on the drawings provided to us, it was noted that several horizontal bends are proposed which may require restraint in addition to that supplied by the pipe bearing on the backfill. In general, thrust blocks, and restrained joints are common methods of supplying additional reaction. However, we understand that restrained joints are planned for the pipe restraint and are discussed below:

Restrained Joints. Restrained joints, allowing thrust and shear forces to be transmitted across the pipe joints, are employed to allow a number of pipe sections to act integrally in bearing. The equations necessary to determine the restrained pipe length on each side of the bend is given below:

$$\mathrm{L} = \frac{PA \quad Sin\,(\theta/2)}{f\ (2\,W_e + W_p + W_w)} \qquad \text{(Reference 4)}$$

where L = restrained pipe length on each side of the bend, in feet

P = internal pressure, in pounds per square inch

A = cross sectional area of first unrestrained pipe joint, in square inches

θ = deflection angle of bend, in degrees

f = co-efficient of friction between pipe and soil (recommended 0.3)

W_e = over burden load, in pounds per linear foot = $\gamma_b B_C H$

W_p = weight of pipe, in pounds per linear foot

W_w = weight of water in pipe, in pounds per linear foot

γ_b = wet unit weight of backfill material in pounds per cubic foot (recommended 120 pcf)

B_c = pipe outside diameter, in feet

H = earth cover, in feet

5.6 Influence of Tunneling on Adjacent Structures

Surface and near-surface structures near the tunnel alignment consist primarily of public utilities, bayou and private pipelines.

Ground movement, in terms of loss of ground or ground lost, is commonly associated with soft ground tunneling. If such ground movement is excessive, it may cause damage to the structures, roads and services located above the tunnel. While ground movement cannot be eliminated, it can be controlled within certain limits by the use of proper construction techniques and good quality workmanship. These include, but are not limited to, prevention of excessive ground loss during tunneling with the use of grouting and filling the annular space between the pipe or casing and the surrounding soil and prevention of undue loss of fines through dewatering.

The selection and execution of tunneling methods that are best suited to anticipated ground conditions along the proposed tunnel are, in fact, the contractor's primary contribution to successful completion of the proposed tunnel. On review of the boring logs, the ground conditions for tunneling (excavation face) along Hunting Bayou crossing (borings GWL-3 and GWL-5) will be through dense to very dense sandy silt and silty sand with medium stiff to stiff lean clay and sandy lean clay near the crown of the pipe. The ground at this segment may be expected to behave as firm to raveling ground with possible cohesive running to flowing ground near the invert (without dewatering) or raveling to cohesive running ground near the invert (with dewatering). The ground conditions for tunneling (excavation face) along private pipelines crossing (boring GWL-4) will be primarily through medium stiff to stiff sandy lean clay and the ground may be expected to behave as firm (stable) ground with possible swelling. However due to spacing of borings, soil conditions other than those encountered in borings could exist. **In view of silty sands and sandy silts encountered within the tunnel diameter near borings GWL-3 and GWL-4, dewatering is recommended in these areas.**

The proposed tunnel is parallel with or crosses beneath a number of water, gas, power and telephone lines. The largest potential problems from utilities may result from:

- Leakage water pipes
- Gas pipe breakage leading to a potential problem
- Breakage of storm and sanitary sewers

In general, it is the contractor's responsibility to investigate these and other possible third party interactions along the proposed tunnel alignment and to accommodate all of these interactions with the use of good construction methods.

5.7 Lateral Earth Pressure Diagrams

Based on information provided to us, the structures for this project will consist of Air Vacuum Valve w/service manhole and access manholes.

The pressure diagrams provided on Figures 5.1 through 5.3 can be used for the design of braced excavation. The lateral earth pressure diagrams presented on Figures 10.1 through 10.3 (Reference 1) are applicable for the design of the permanent walls of the structures.

5.8 Allowable Bearing Pressures and Hydrostatic Uplift Resistance

5.8.1 Allowable Bearing Pressures. Based on the soil conditions revealed by the borings GWL-3 and GWL-4, the structure bases will be in soft to stiff sandy lean clay and very dense sandy silt.

The bases of structures placed at approximate depths ranging from 10 to about 40 feet at the various locations may be proportioned for an allowable (net) bearing pressure as given below.

Manhole	**Nearest Boring No.**	**Approximate Foundation Depths, feet**	**Allowable (Net) Bearing Pressure, psf**
Air Vacuum Valve w/service manhole	GWL-3	10	1500
Access manholes on either side of tunnel crossing of Hunting Bayou	GWL-3 and GWL-4	33	1500

The allowable bearing pressures include a factor of safety of 2.0. The recommendations of the allowable bearing pressures given above assume that the final bearing surface consists of undisturbed natural soils, underlying transmissive zones are properly pressure-relieved, and stable undisturbed bearing surfaces are attained.

5.8.2 Hydrostatic Uplift Resistance. Structures extending below the groundwater level should be designed to resist uplift pressure resulting from excess piezometric head. Design uplift pressures should be computed based on the assumption that the water table is at ground surface. To resist the hydrostatic uplift at the bottom of the structures, one of the following sources of resistance can be utilized in each of the designs.

a. Dead weight of structure,
b. Weight of soil above base extensions plus weight of structure, or
c. Soil-wall friction plus dead weight of structure.

The uplift force and resistance to uplift should be computed as detailed on Figure 11 (Reference 5). In determining the configuration and dimensions of the structure using one of the approaches presented on Figure 11, the following factors of safety are recommended.

a. dead weight of concrete structure, S_{f1} = 1.10,

b. weight of soil(backfill) above base extension, S_{f2} = 1.5, and

c. soil-wall friction, S_{f3} = 3.0.

Friction resistance should be discounted for the upper 5 feet, since this zone is affected by seasonal moisture changes.

5.8.3 Groundwater Control During Construction. Excavations will encounter groundwater seepage. It is our opinion that in cohesive soils (for the excavation depths of 10 to 15 feet), groundwater may be collected in excavation bottom sumps for pumped disposal. **However, due to cohesionless soils encountered between depth of 10 and 15 feet and 35 to 50 feet in boring GWL-3 and GWL-4, dewatering will be required to lower the ground water level at least 5 feet below the bottom of excavation.**

It is recommended that the actual groundwater conditions be verified at the time of construction and the groundwater control be performed in general accordance with City of Houston Standard Specifications, Section 01578, "Control of Groundwater and Surface Water."

5.9 Protection of Below Grade Structures

The design of proper means for the protection of below grade structures will depend upon the potential of the aggressivity or corrosivity of soil and groundwater properties. The aggressive test or corrosivity test of soil and the design of the protection of below grade structures is beyond the scope of services for this study.

6.0 LIMITATIONS

The description of subsurface conditions and the design information contained in this report are based on the test boring made at the time of drilling at specific locations. However, some variation in soil conditions may occur between test boring. Should any subsurface conditions other than those described in our boring be encountered, Geotest should be immediately notified so that further investigation and supplemental recommendations can be provided.

The depth of the groundwater level may vary with changes in environmental conditions such as frequency and magnitude of rainfall. The stratification lines on the log of borings represent the approximate boundaries between soil types, however, the transition between soil types may be more gradual than depicted.

7.0 AUTHORIZATIONS AND CREDITS

LAN was selected by City of Houston to provide engineering design and construction program management services in support Surface Water Transmission Program (SWTP) Projects. LAN then selected Geotest Engineering, Inc. to provide geotechnical engineering services related to the design and construction of 84-inch Water Line Interconnect project.

This report has been prepared for the exclusive use of LAN or City of Houston for the design and construction of the SWTP 84-inch Water Line Interconnect project.

This report shall not be reproduced without the written permission of Geotest Engineering, Inc., LAN or the City of Houston.

8.0 REFERENCES

1. Das, Braja M. (1999), *Principles of Foundation Engineering*, 4th Edition, Brooks/Cole Publishing Company, Pacific Grove, CA.
2. Department of the Navy (1982), *Foundations and Earth Structures Design Manual 7.2*, Naval Facilities Engineering Command, Alexandria, VA.
3. American Water Works Association, *Manual of Water Supply Practices, Steel Pipe-A Guide for Design and Installation*, AWWA Manual M11, Thrid Edition, American Water Works Association, Denver, CO.
4. American Water Works Association, *Manual of Water Supply Practices, Concrete Pressure Pipe,* AWWA Manual M9, Second Edition, American Water Works Association, Denver, CO.
5. Geotest Engineering, Inc., Houston, Texas.

ILLUSTRATIONS

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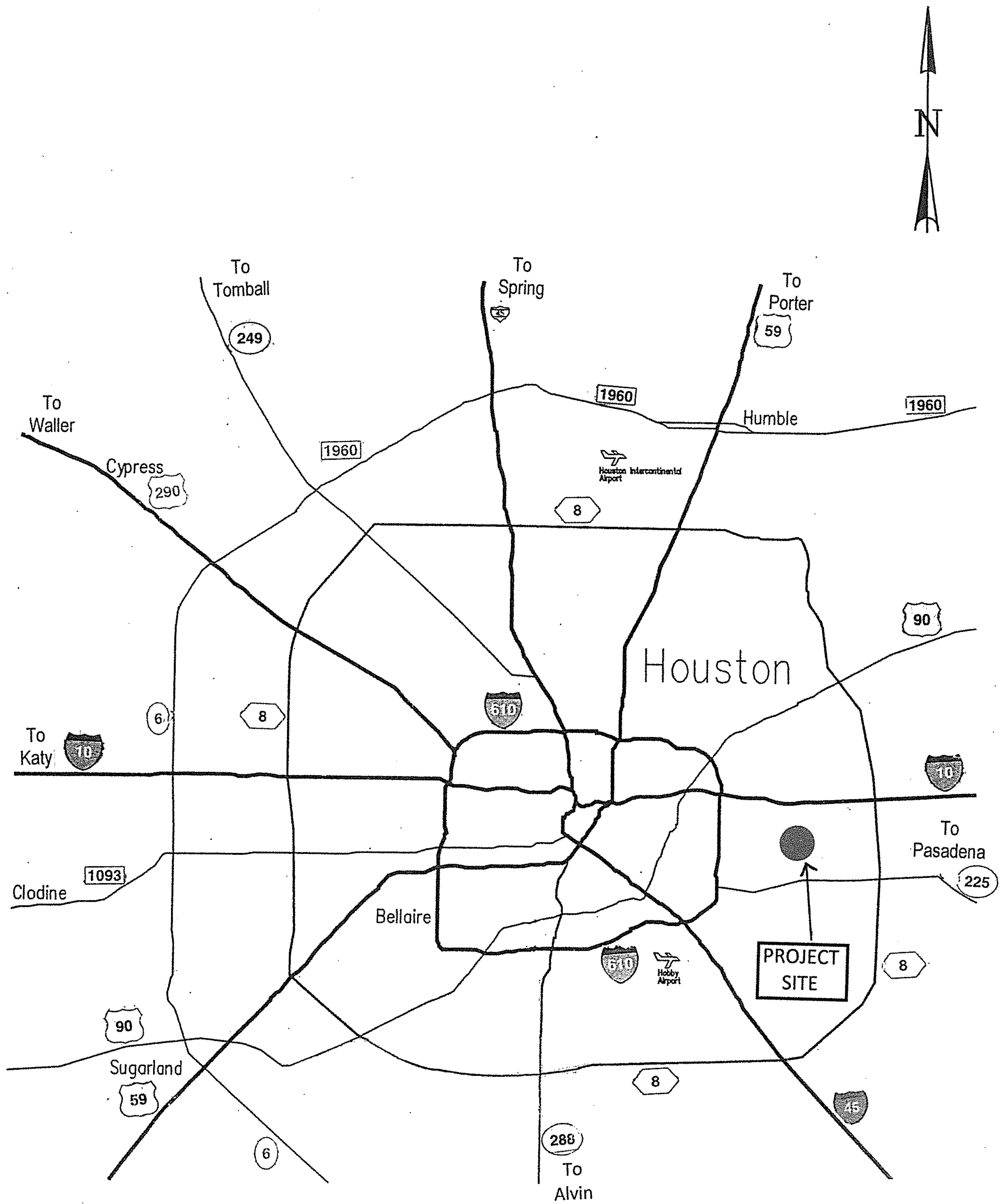

VICINITY MAP

(NOT TO SCALE)

Geotest Engineering, Inc.

FIGURE 1

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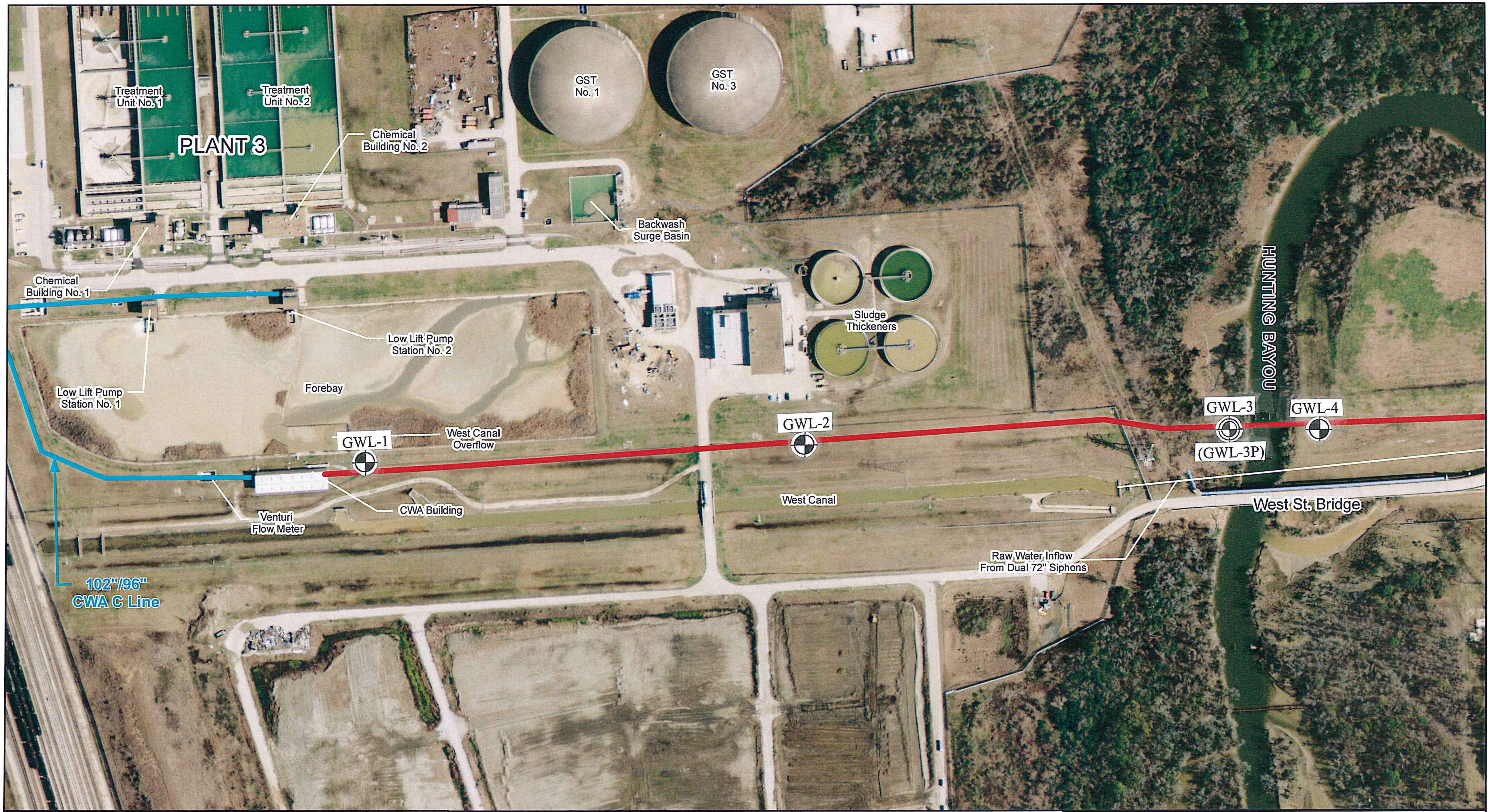


LEGEND

Proposed Alignment

102/96-in CWA "C" Line

Boring Location

Boring with Piezometer

N E S W

0 100 200 400 Feet

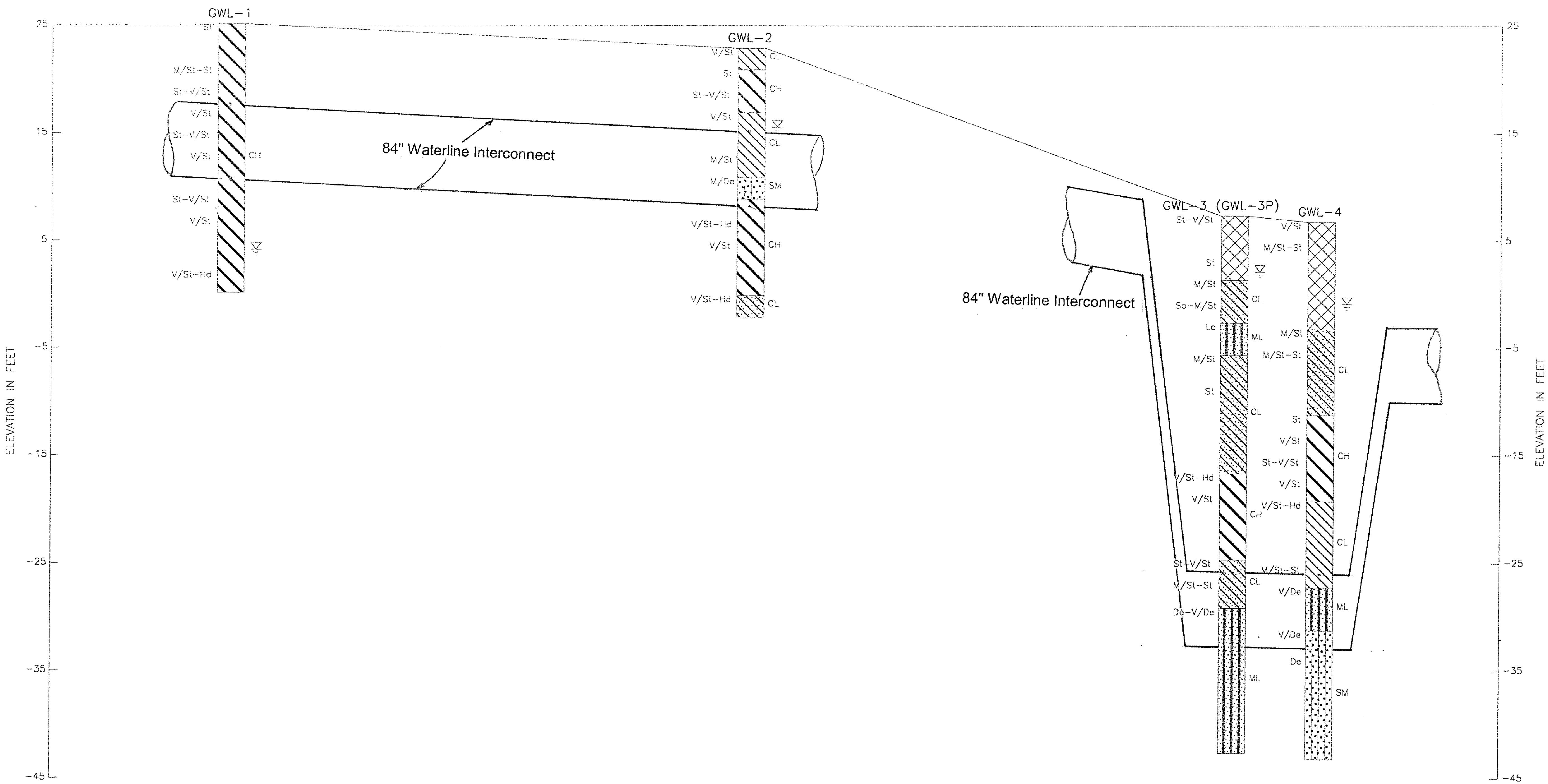
EAST WATER PURIFICATION PLANT (EWPP)

WBS No. S-000902-0132-3
84-inch Interconnection @ EWPP

BORING LOCATIONS

Path: L:\130-10557-020\9-0-Non-Projectwise_Data\9-01-GIS\MXD\EWPP Interconnect _Boring Locations - 132.mxd Date Saved: 1/23/2013 5:45:03 PM

FIGURE 2



GENERAL NOTES:

1. See Figure 2 for approximate location of borings and profile section.
2. Data concerning subsurface conditions have been obtained at boring locations only. Actual conditions between borings may differ from the profile shown here.
3. See logs of boring for detailed description of soils encountered in each borehole.
4. See Figure 4 for symbols and abbreviations used on this profile.
5. Ground surface elevation at each boring location was based on survey data provided to us by Lan, Inc.

BORING LOG PROFILE

84" Waterline Interconnect

0 100 200 300 400

HORIZONTAL SCALE IN FEET

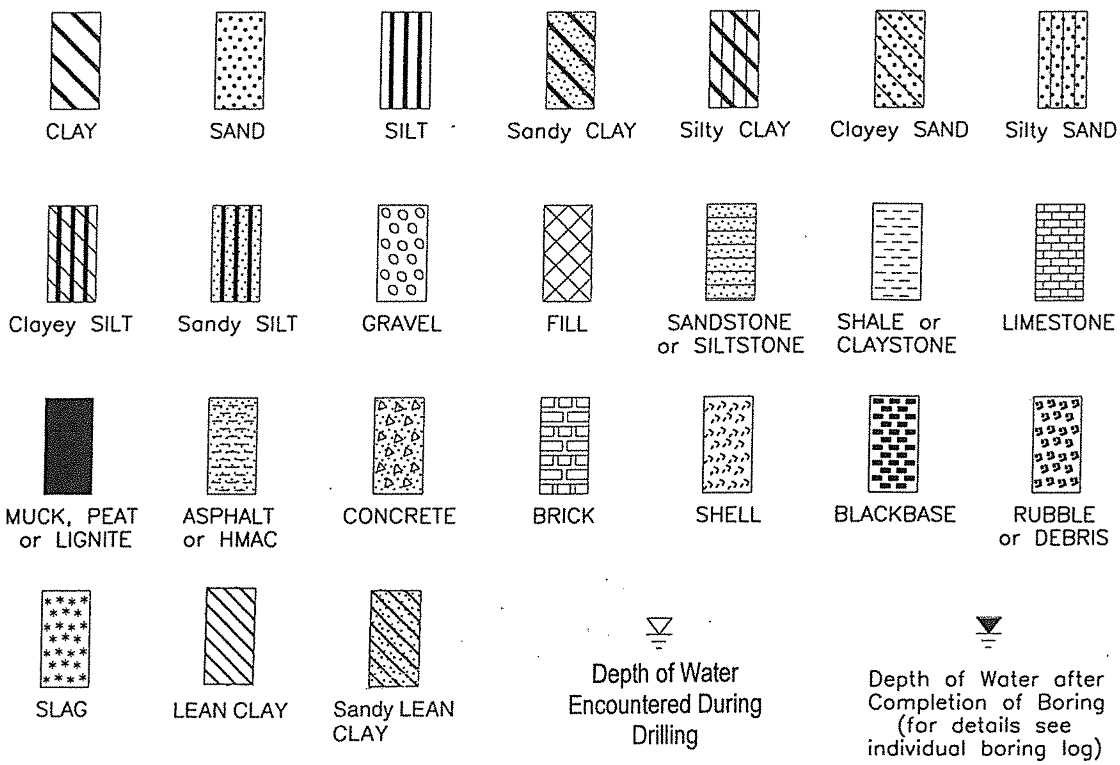
Job No. 1140193701

Geotest Engineering, Inc.

FIGURE 3

SYMBOLS AND ABBREVIATIONS USED ON BORING LOG PROFILE

LEGEND



ABBREVIATIONS USED FOR CONSISTENCY/DENSITY

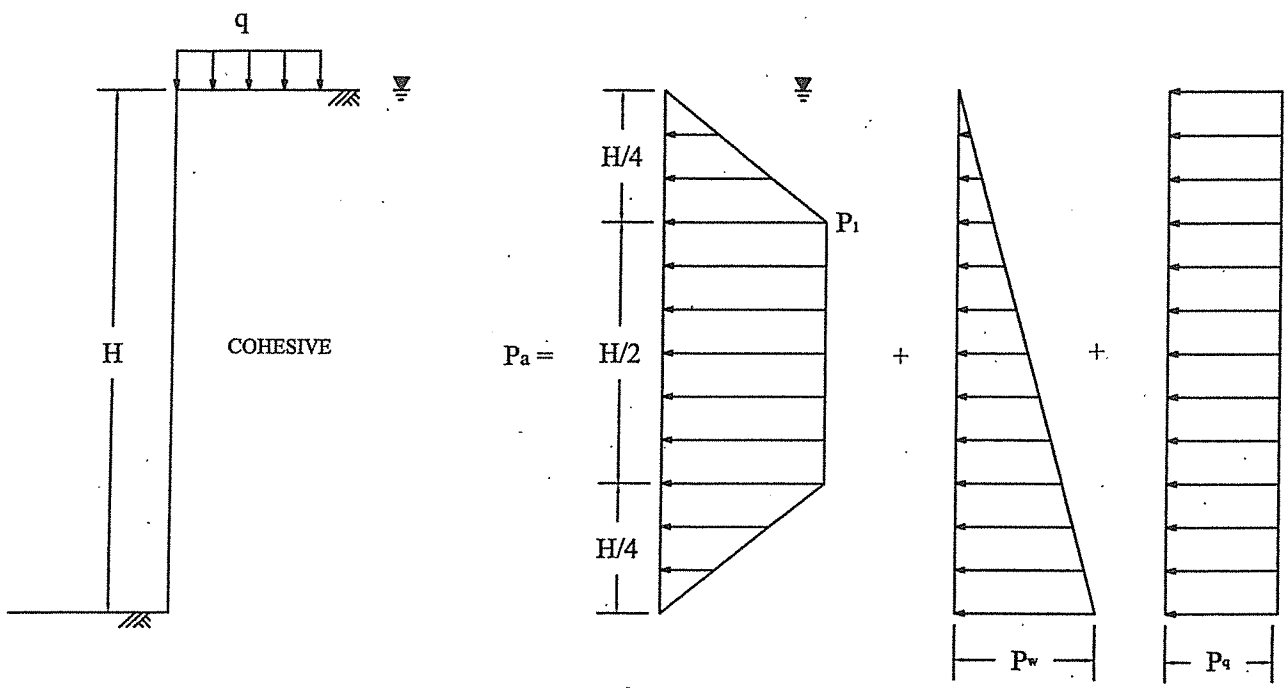
COHESIVE SOILS

V/So : Very Soft
So : Soft
Fm : Firm
M/St : Medium Stiff
St : Stiff
V/St : Very Stiff
Hd : Hard
V/Hd : Very Hard

COHESIONLESS SOILS

V/Lo : Very Loose
Lo : Loose
S/Co : Slightly Compact
Co : Compact
M/De : Medium Dense
De : Dense
V/De : Very Dense

Job No. 1140193701



TYPICAL SOIL PARAMETERS

See Table 2 for typical values of soil parameters

BRACED WALL

For $\gamma H/c \leq 4$

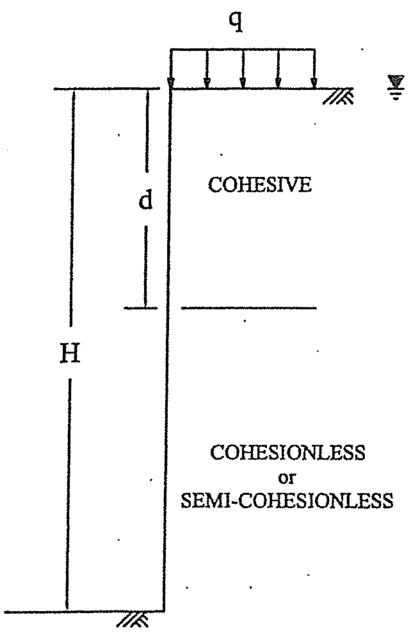
$P_1 = 0.3\ \gamma_c'\ H$
$P_w = \gamma_w\ H = 62.4\ H$
$P_q = 0.5\ q$

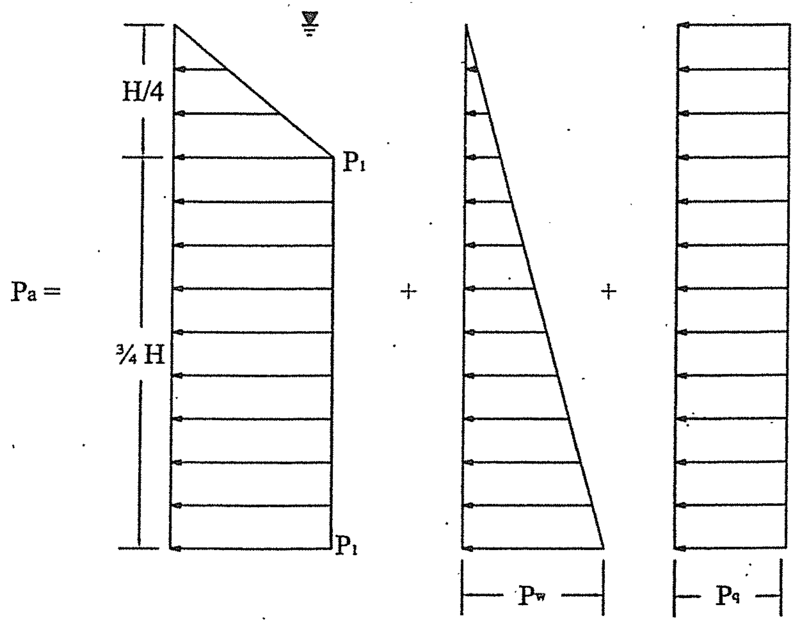
Where:

γ_c' = Submerged unit weight of cohesive soil, pcf;
γ_w = Unit weight of water, pcf;
q = Surcharge load at surface, psf;
P_a = Lateral pressure, psf;
P_1 = Active earth pressure, psf;
P_q = Horizontal pressure due to surcharge, psf;
P_w = Hydrostatic pressure due to groundwater, psf;
H = Depth of braced excavation, feet
c = Shear strength of cohesion soil, psf;

EXCAVATION SUPPORT EARTH PRESSURE

SUBMERGED COHESIVE SOIL





TYPICAL SOIL PARAMETERS

BRACED WALL

See Table 2 for typical values of soil parameters

$$\gamma'_{avg} = \frac{\gamma_c'\, d + \gamma_s'\, (H-d)}{H}$$

$P_1 = 0.3\ \gamma'_{avg}\ H$
$P_w = 62.4\ H$
$P_q = 0.5\ q$

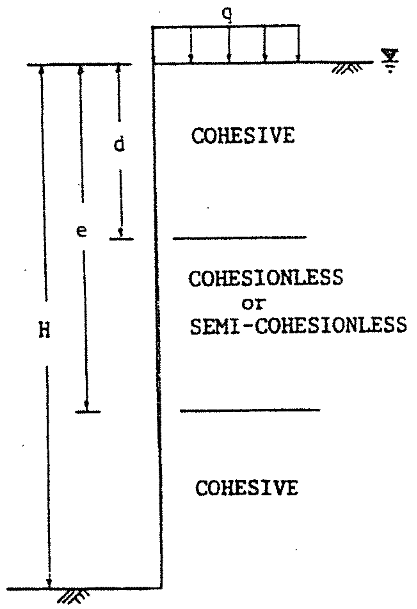
Where:

γ_c' = Submerged unit weight of cohesive soil, pcf;
γ_s' = Submerged unit weight of cohesionless soil, pcf;
γ'_{avg} = Average submerged unit weight of soils, pcf;
q = Surcharge load at surface, psf;
P_a = Lateral pressure, psf;
P_1 = Active earth pressure, psf;
P_q = Horizontal pressure due to surcharge, psf;
P_w = Hydrostatic pressure due to groundwater, psf;
H = Depth of braced excavation, feet

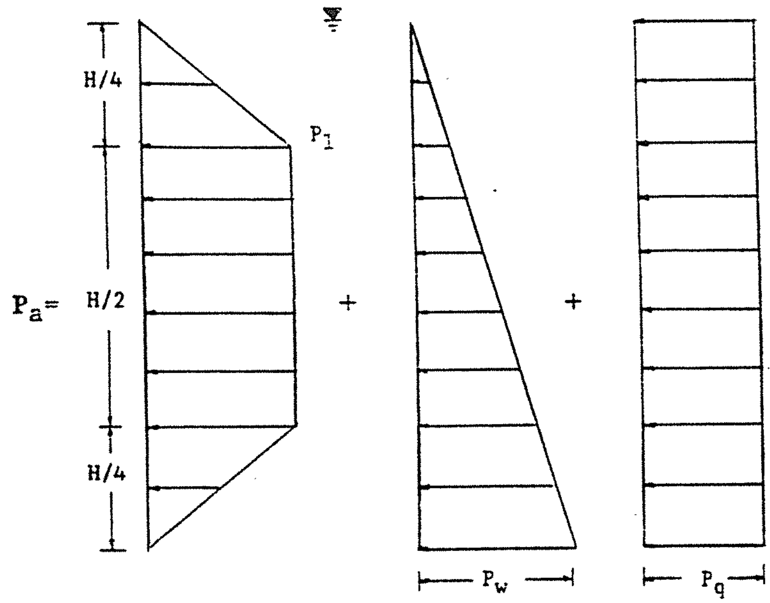
EXCAVATION SUPPORT EARTH PRESSURE

SUBMERGED COHESIVE SOIL OVER
COHESIONLESS OR SEMI-COHESIONLESS SOIL

Job No. 1140193701



TYPICAL SOIL PARAMETERS



BRACED WALL

See Table 2 for typical values of soil parameters

$P_1 = 0.3\ \gamma'_{avg}\ H$

$P_w = \gamma_w\ H = 62.4\ H$

$P_q = 0.5_q$

$$\gamma'_{avg} = \frac{\gamma_c'\ d + \gamma_s'\ (e-d) + \gamma_c'\ (H-e)}{H}$$

$\gamma_w = 62.4$ pcf

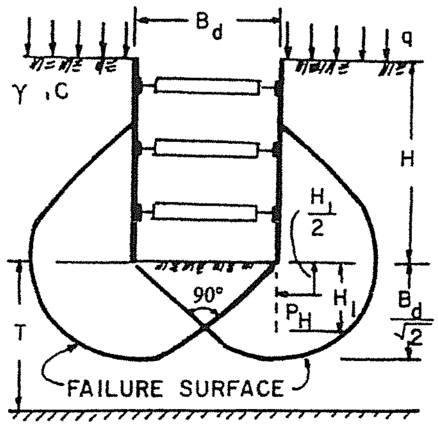
Where:

γ_c' = Submerged unit weight of cohesive soil, pcf ;
γ_s' = Submerged unit weight of cohesionless or semi-cohesionless soil, pcf ;
γ_w = Unit weight of water, pcf;
γ'_{avg} = Average submerged unit weight of soil, pcf ;
q = Surcharge load at surface, psf;
P_a = Lateral pressure, psf;
P_1 = Active earth pressure, psf;
P_q = Horizontal pressure due to surcharge, psf;
P_w = Hydrostatic pressure due to groundwater, psf;
H = Depth of braced excavation, feet

EXCAVATION SUPPORT EARTH PRESSURE

SUBMERGED COHESIVE SOIL
INTERBEDDED WITH COHESIONLESS OR
SEMI-COHESIONLESS SOIL

CUT IN COHESIVE SOIL,
DEPTH OF COHESIVE SOIL UNLIMITED ($T > 0.7\ B_d$)
L = LENGTH OF CUT



If sheeting terminates at base of cut:

$$\text{Safety factor, } F_S = \frac{N_C C}{\gamma H + q}$$

N_C = Bearing capacity factor, which depends on dimensions of the excavation : B_d, L and H (use N_C from graph below)

C = Undrained shear strength of clay in failure zone beneath and surrounding base of cut

γ = Wet unit weight of soil (see Table 2)

q = Surface surcharge (assume q = 500 psf)

If safety factor is less than 1.5, sheeting or soldier piles must be carried below the base of cut to insure stability - (see note)

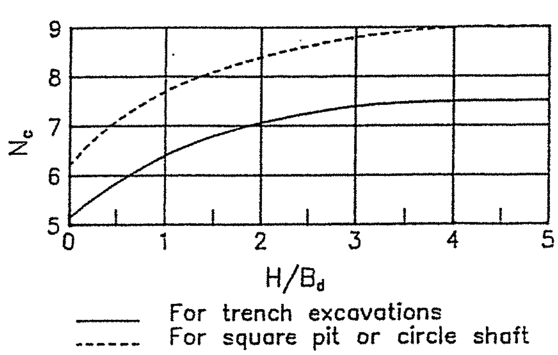
$$H_1 = \text{Buried length} = \frac{B_d}{2} \geq 5 \text{ feet}$$

Note : If soldier piles are used, the center to center spacing should not exceed 3 times the width or diameter of soldier pile .

Force on buried length, P_H:

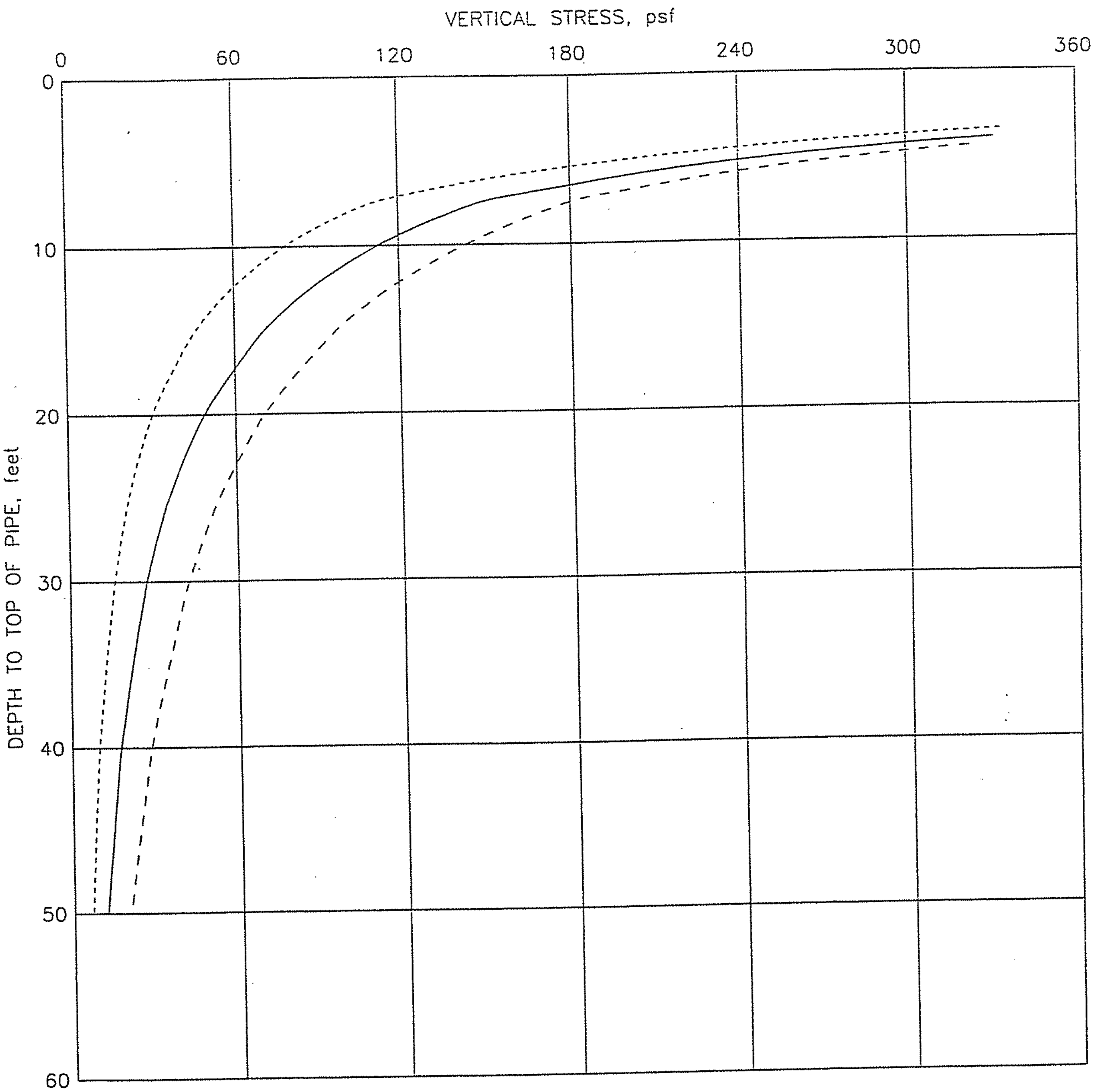
$$\text{If } H_1 > \frac{2}{3}\,\frac{B_d}{\sqrt{2}}, \quad P_H = 0.7\,(\gamma H B_d - 1.4CH - \pi C B_d) \text{ in lbs/ linear foot}$$

$$\text{If } H_1 < \frac{2}{3}\,\frac{B_d}{\sqrt{2}}, \quad P_H = 1.5H_1\left(\gamma H - \frac{1.4CH}{B_d} - \pi C\right) \text{ in lbs/ linear foot}$$



STABILITY OF BOTTOM FOR BRACED CUT

Job No. 1140193701

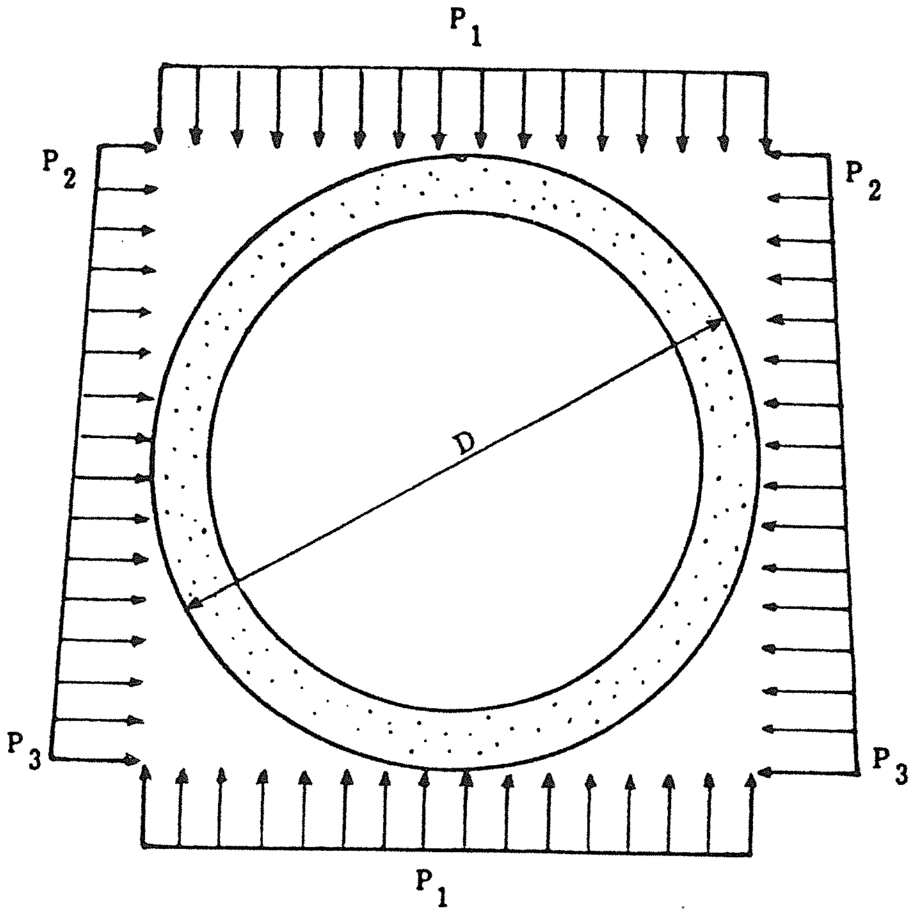


Legend:
- ------ One passing truck
- ______ Two passing trucks
- _ _ _ Four passing trucks

Notes:
1. The vertical stress was estimated using AASHTO H20 or HS20 truck axle loadings on paved surfaces.
2. Impact factor was included in the vertical stress.

VERTICAL STRESS ON PIPES
DUE TO TRAFFIC LOADS

Job No. 1140193701



$$P_1 = [(H + \frac{D}{2}) \times (\gamma - \gamma_w) + D_w \times \gamma_w] + q_s \text{, for } D_w < H + \frac{D}{2}$$

$$P_1 = [(H + \frac{D}{2}) \times \gamma] + q_s \text{, for } D_w \geq H + \frac{D}{2}$$

$$P_2 = (H \times \gamma) + q_s$$

$$P_3 = [(H + D) \times \gamma] + q_s$$

Where: P_1, P_2, P_3 = Tunnel liner load, psf.

D = Tunnel outside diameter, ft.

H = Depth to top of tunnel; ft.

D_w = Depth to ground water level; ft.

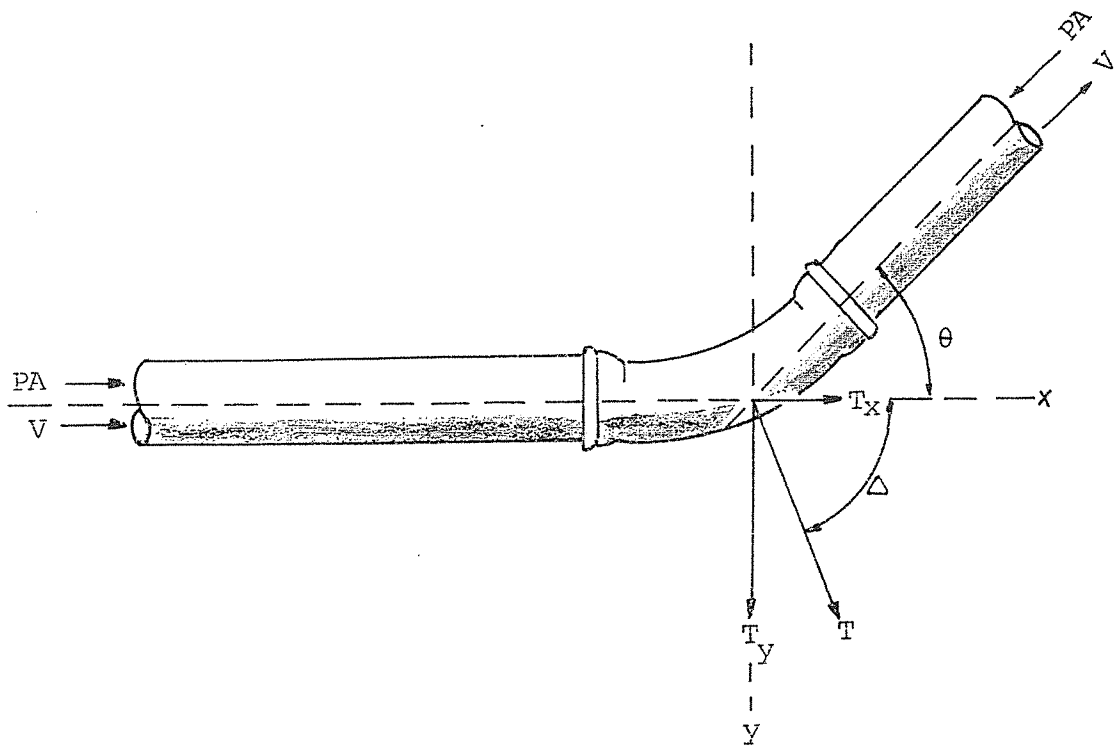
γ = Wet unit weight of soil, pcf (see Table 3)

γ_w = Unit weight of water, 62.4 pcf

q_s = Surcharge load, psf.

K_o = Coefficient of Lateral Earth Pressure at rest

TUNNEL LINER LOADS



T_x = PA (1 - COS θ)

T_y = PA SIN θ

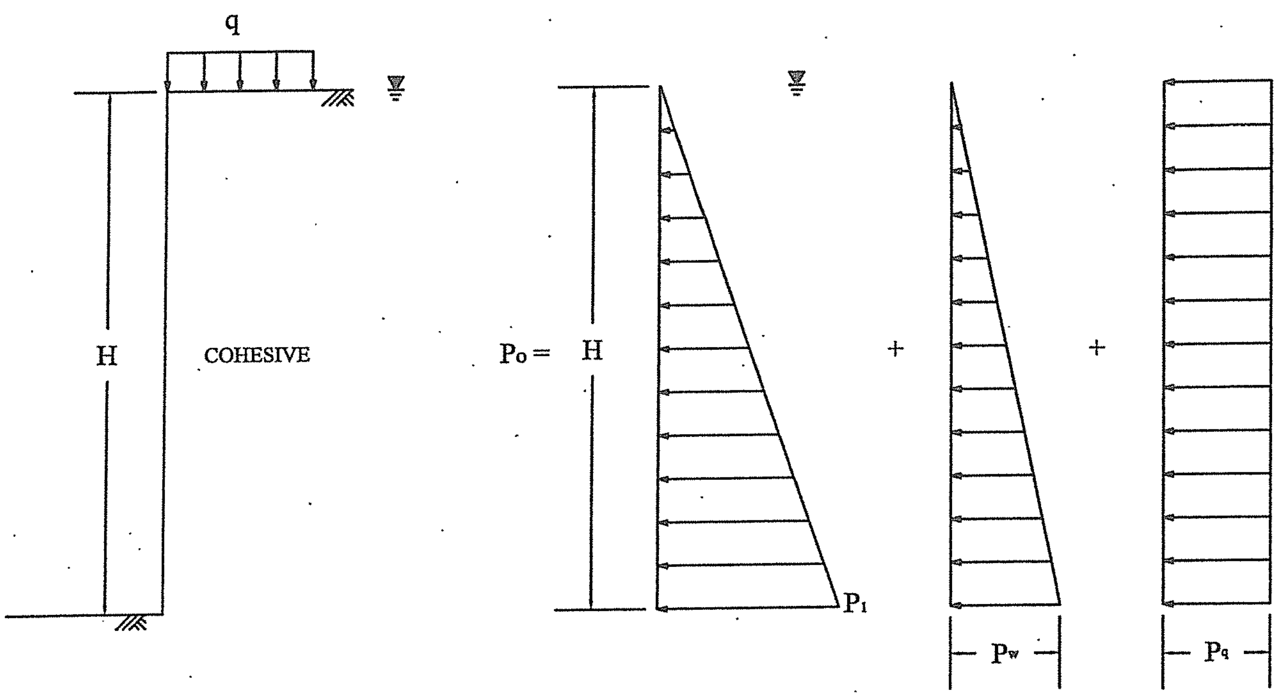
T = 2 PA SIN $\frac{\theta}{2}$

Δ = (90 - $\frac{\theta}{2}$)

Where:

- T is the resultant force on the bend
- T_x is the component of thrust force in x-direction
- T_y is the component of thrust force in y-direction
- P is the maximum sustained pressure
- A is the pipe cross-sectional area
- θ is the bend deflection angle
- Δ is the angle between T and X-axis
- V is the fluid velocity

THRUST FORCES ACTING ON A BEND



TYPICAL SOIL PARAMETERS

See Table 2 for typical values of soil parameters

$K_{oc} = 1.0$

PERMANENT WALL

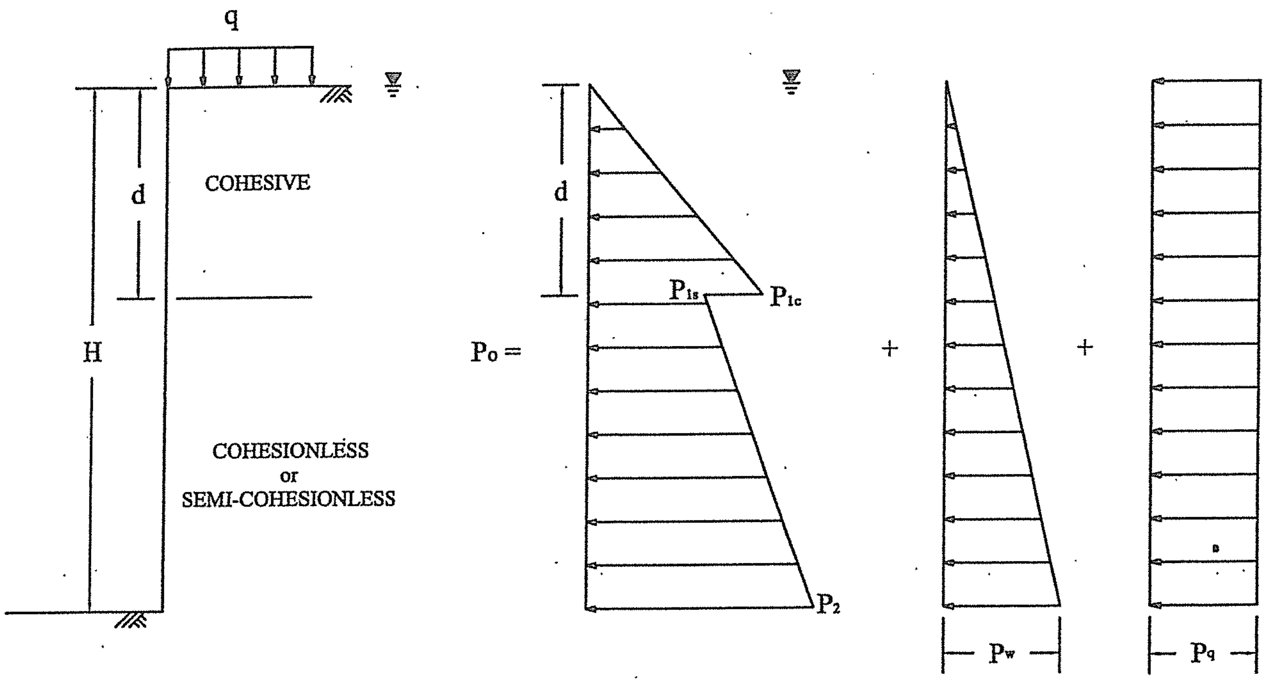
$P_1 = K_{oc}\, \gamma_c'\, H$
$P_w = \gamma_w\, H = 62.4\, H$
$P_q = 0.5\, q$

Where:

γ_c' = Submerged unit weight of cohesive soil, pcf;
K_{oc} = Coefficient of at-rest earth pressure in cohesive soil;
γ_w = Unit weight of water, pcf;
q = Surcharge load at surface, psf;
P_o = Lateral pressure, psf;
P_1 = At-rest earth pressure, psf;
P_q = Horizontal pressure due to surcharge, psf;
P_w = Hydrostatic pressure due to groundwater, psf;
H = Depth of excavation, feet

LATERAL EARTH PRESSURE DIAGRAM FOR PERMANENT WALL

SUBMERGED COHESIVE SOIL



TYPICAL SOIL PARAMETERS

PERMANANT WALL

See Table 2 for typical values of soil parameters

$K_{oc} = 1.0$
$K_{os} = 1\text{-}\sin\phi_s$

$P_{1c} = \gamma_c'\, d\, K_{oc}$
$P_{1s} = \gamma_c'\, d\, K_{os}$
$P_2 = [\gamma_c'\, d + \gamma_s'\,(H\text{-}d)]\, K_{os}$
$P_w = \gamma_w\, H = 62.4\, H$
$P_q = 0.5\, q$

Where:

γ_c' = Submerged unit weight of cohesive soil, pcf;
γ'_s = Submerged unit weight of cohesionless or semi-cohesionless soil, pcf;
ϕ_s = Internal friction angle of cohesionless or semi-cohesionless soil, degree;
K_{oc} = Coefficient of at-rest earth pressure in cohesive soil;
K_{os} = Coefficient of at-rest earth pressure in cohesionless or semi-cohesionless soil;
γ_w = Unit weight of water, pcf;
q = Surcharge load at surface, psf;
P_o = Lateral pressure, psf;
P_i, P_{ic}, P_{is} = At-rest earth pressure, psf; i = 1, 2;
P_q = Horizontal pressure due to surcharge, psf;
P_w = Hydrostatic pressure due to groundwater, psf;
H = Height of wall, feet

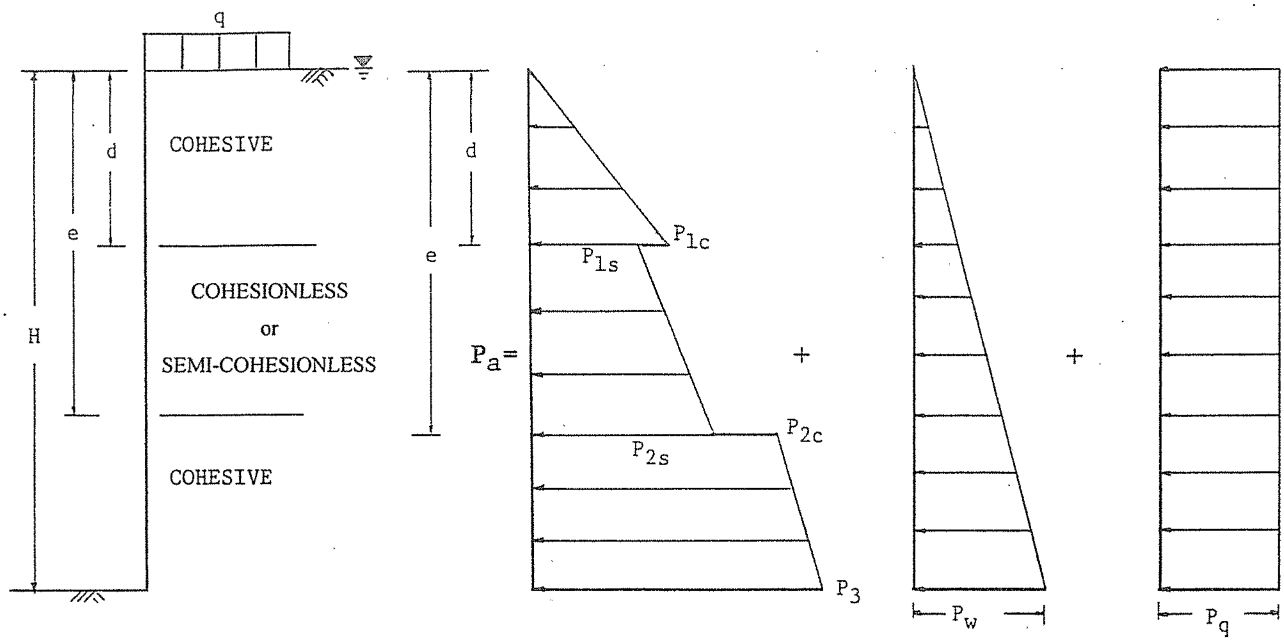
LATERAL EARTH PRESSURE DIAGRAM FOR PERMANENT WALL

SUBMERGED COHESIVE SOIL OVER COHESIONLESS OR SEMI-COHESIONLESS SOIL

Geotest Engineering, Inc.

FIGURE 10.2

Job No. 1140193701



TYPICAL SOIL PARAMETERS

See Table 2 for typical values of soil parameters

$K_{oc} = 1.0$

$K_{os} = 1 - \sin\phi_s$

$\gamma_w = 62.4$ psf

PERMANENT WALL

$P_{1c} = \gamma'_c \, d \, K_{oc}$

$P_{1s} = \gamma'_c \, d \, K_{os}$

$P_{2s} = P_{1s} + \gamma'_s \, (e\text{-}d) \, K_{os}$

$P_{2c} = [\gamma'_c \, d + \gamma'_s \, (e\text{-}d)] \, K_{oc}$

$P_3 = [\gamma'_c \, d + \gamma'_s \, (e\text{-}d) + \gamma'_c \, (H\text{-}e)] \, K_{oc}$

$P_w = \gamma_w H = 62.4 H$

$P_q = 0.5 \, q$

Where:

γ_c' = Effective unit weight of cohesive soil, pcf;
γ_s' = Effective unit weight of cohesionless or semi-cohesionless soil, pcf;
ϕ_s = Internal friction angle of cohesionless or semi-cohesionless soil, degree;
K_{oc} = Coefficient of earth pressure at rest in cohesive soils;
Ko_{as} = Coefficient of earth pressure at rest in cohesionless or semi-cohesionless soil;
γ_w = Unit weight of water, pcf;
q = Surcharge load at surface, psf;
P_a = Lateral pressure, psf;
P_i, P_{ic}, P_{is} = Earth pressure at rest, psf; i = 1, 2, 3;
P_q = Horizontal pressure due to surcharge, psf;
P_w = Hydrostatic pressure due to groundwater, psf;
H = Height of wall, feet

LATERAL EARTH PRESSURE DIAGRAM FOR PERMANENT WALL

SUBMERGED COHESIVE SOIL
INTERBEDDED WITH COHESIONLESS
OR SEMI-COHESIONLESS SOIL

Geotest Engineering, Inc.

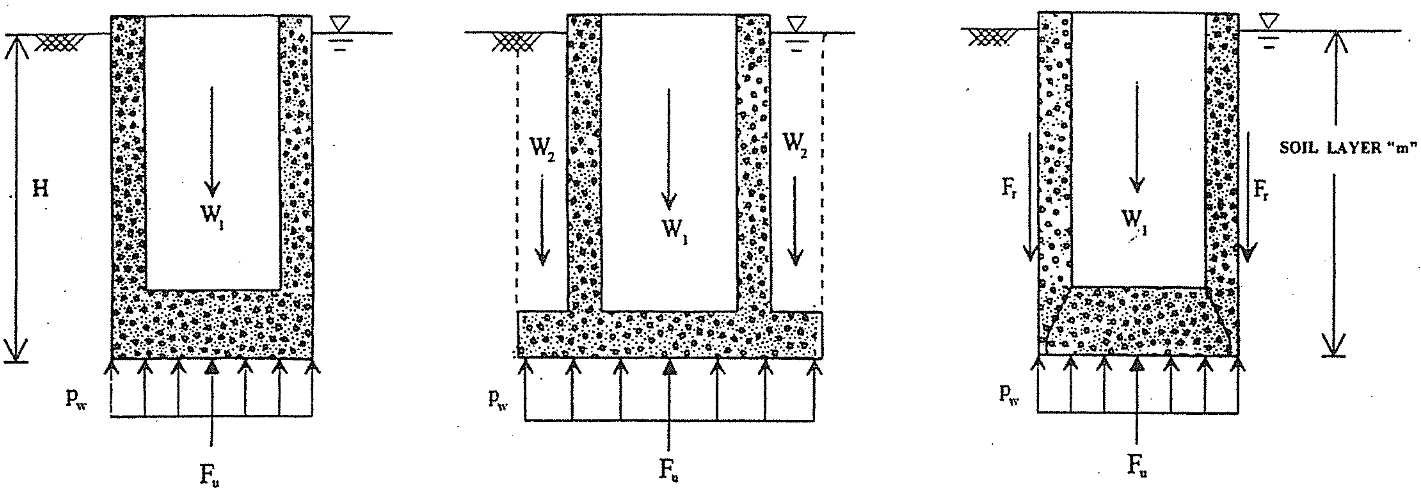
FIGURE 10.3

Job No. 1140193701

(a) DEAD WEIGHT OF STRUCTURE

(b) WEIGHT OF SOIL ABOVE BASE EXTENSION PLUS DEAD WEIGHT OF STRUCTURE

(c) SOIL-WALL FRICTION PLUS DEAD WEIGHT OF STRUCTURE



(a)	(b)	(c)
$P_w = H\gamma_w$	$P_w = H\gamma_w$	$P_w = H\gamma_w$
$F_u = A_b P_w$	$F_u = A_b P_w$	$F_u = A_b P_w$
$\frac{W_1}{Sf_1} = F_u$	$\frac{W_1}{Sf_1} + \frac{W_2}{Sf_2} = F_u$	$\frac{W_1}{Sf_1} + \frac{F_r}{Sf_3} = F_u$

Predominantly Cohesive Soils, $F_r = \alpha c_m A_m$

Predominantly Cohesionless Soils, $F_r = p_m A_m K \tan \delta_m$

See Table 2 for typical values of soil parameters

Where:

A_b	=	area of base, sq. ft.
A_m	=	cylindrical surface area of layer "m" , sq. ft.
c_m	=	undrained cohesion of soil layer "m", psf.
F_u	=	hydrostatic uplift force, lbs.
F_r	=	frictional resistance, lbs.
H	=	height of buried structure, ft.
K	=	coefficient of lateral pressure = 0.5.
p_m	=	average overburden pressure for layer "m," psf.
p_w	=	hydrostatic uplift pressure, psf.
$Sf_{1,2,3}$	=	factor of safety.
W_1	=	dead weight of concrete structure, lbs.
W_2	=	weight of backfill above base extension, lbs.
α	=	cohesion reduction factor = 0.5.
δ_m	=	friction angle between soil layer "m" and concrete wall, degrees = 0.75 ϕ_m
ϕ_m	=	internal angle of friction of soil layer "m", degrees.
γ_w	=	unit weight of water = 62.4 pcf.

UPLIFT PRESSURE AND RESISTANCE

TABLES

	Table
Summary of Field Exploration	1
Geotechnical Design Parameter Summary Open-Cut Excavation	2
Geotechnical Design Parameter Summary – Trenchless Installation	3.1 and 3.2

TABLE 1

SUMMARY OF FIELD EXPLORATION

Boring No.	Depth (feet)	Northing	Easting	Ground Surface Elevation
GWL-1	25	13839966.13	3169135.67	25.12
GWL-2	25	13838999.05	3169181.89	22.88
GWL-3 (GWL-3P)	50	13838098.33	3169183.95	7.38
GWL-4	50	13837935.00	3169175.14	6.79

Note: The survey information of completed borings were provided to us by LAN, Inc.

TABLE 2

GEOTECHNICAL DESIGN PARAMETER SUMMARY
OPEN-CUT EXCAVATION

Boring Nos.	Stratigraphic Unit	Range of Depths, ft	Wet Unit Weight, γ, pcf	Submerged Unit Weight, γ', pcf	Undrained Cohesion, psf	Internal Friction Angle, ϕ, degree
GWL-1	Cohesive	0-6	115	58	800	--
		6-12	130	65	1,500	--
		12-20	123	62	2,000	--
		20-25	127	65	3,500	--
GWL-2	Cohesive	0-6	124	62	1,000	--
		6-10	120	58	2,000	--
		10-12	126	54	600	--
	Cohesionless	12-14	117	54	--	30
	Cohesive	14-23	130	58	3,000	--
		23-25	125	60	2,000	--
GWL-3	Cohesive	0-5	124	62	1,600	--
		5-10	133	70	600	--
	Cohesionless	10-13	100	38	--	25
	Cohesive	13-24	130	67	700	--
		24-32	129	67	220	--
		32-36	129	67	1,000	--
	Cohesionless	36-50	115	52	--	35
GWL-4	Cohesive	0-8	131	65	1,000	--
		8-18	126	64	500	--
		18-25	130	68	1,400	--
		25-32	135	73	3,000	--
		32-34	135	73	600	--
	Cohesionless	34-38	114	52	--	35
		38-50	133	71	--	35

Notes:

1. Cohesive soils include Fat Clay, Lean Clay and Sandy Lean Clay.
2. Cohesionless soils include Silty Sand and Sandy Silt.

TABLE 3.1

GEOTECHNICAL DESIGN PARAMETER SUMMARY
TRENCHLESS INSTALLATION – HUNTING BAYOU CROSSING
(Based on Borings GWL-3 and GWL-4)

PROPERTY		COHESIVE SOILS [1]	COHESIONLESS SOILS [2]
Wet Unit Weight, γ, pcf	0-5	124	--
	5-10	130	--
	10-13	126	100 (GWL-3 only)
	13-25	132	--
	25-32	132	117
	32-35	132	115
	35-38	--	130
	38-50	--	--
Submerged Unit Weight, γ', pcf	0-5	62	--
	5-10	65	--
	10-13	63	38 (GWL-3 only)
	13-25	67	--
	25-32	67	--
	32-35	67	--
	35-38	--	52
	38-50	--	71
Moisture Content (%)	0-5	19	--
	5-10	20	--
	10-13	25	19 (GWL-3 only)
	13-25	21	--
	25-32	21	--
	32-35	21	--
	35-38	--	23
	38-50	--	23
UNDRAINED PROPERTIES			
Undrained Cohesion, c_u, psf	26-32*	2,200	--
	32-35*	1,000	--
	35-38*	--	--
	38-47*	--	--
Angle of Internal Friction, ϕ, degrees	26-32*	--	--
	32-35*	--	--
	35-38*	--	35
	38-47*	--	35
Elastic Modulus, E, psf	26-32*	660,000	--
	32-35*	500,000	--
	35-38*	--	504,000
	38-47*	--	1,064,000
Coefficient of Lateral Earth pressure at Rest, K_o,	26-32*	1.2	--
	32-35*	1.2	--
	35-38*	--	0.43
	38-47*	--	0.43
Poisson's Ratio, μ		0.45	0.3
DRAINED PROPERTIES			
Drained Cohesion, c', psf	26-32*	0	--
	32-35*	0	--
	35-38*	0	--
	38-47*	0	--
Angle of Internal Friction, ϕ', degrees	26-32*	22	--
	32-35*	31	--
	35-38*	--	35
	38-47*	--	35
Elastic Modulus, E, psf	26-32*	396,000	--
	32-35*	300,000	--
	35-38*	--	504,000
	38-47*	--	1,064,000

Notes: 1. Cohesive soils include Fat Clay, Lean Clay and Sandy Lean Clay.
2. Cohesionless soils include Silty Sand and Sandy Silt.
* Tunneling zone between depths of 26 and 47 feet (one bore diameter, but not less than 6 feet, above and below tunnel bore)

TABLE 3.2

GEOTECHNICAL DESIGN PARAMETER SUMMARY
TRENCHLESS INSTALLATION – PRIVATE PIPELINES CROSSING
(Based on Boring GWL-4)

PROPERTY		COHESIVE SOILS [1]	COHESIONLESS SOILS [2]
Wet Unit Weight, γ, pcf	0-8	131	--
	8-18	126	--
	18-25	130	--
	25-32	135	--
	32-34	135	--
	34-38	--	114
	38-50	--	133
Submerged Unit Weight, γ', pcf	0-8	65	--
	8-18	64	--
	18-25	68	--
	25-32	73	--
	32-34	73	--
	34-38	--	52
	38-50	--	71
Moisture Content (%)	0-8	19	--
	8-18	29	--
	18-25	22	--
	25-32	20	--
	32-34	22	--
	34-38	--	23
	38-50	--	24
UNDRAINED PROPERTIES			
Undrained Cohesion, c_u, psf	4-8*	1,000	
	8-18*	500	
	18-25*	1,400	
Angle of Internal Friction, ϕ, degrees	4-8*	--	
	8-18*	--	
	18-25*	--	
Elastic Modulus, E, psf	4-8*	300,000	
	8-18*	250,000	
	18-25*	420,000	
Coefficient of Lateral Earth pressure at Rest, K_o,	4-8*	1.2	
	8-18*	1.2	
	18-25*	1.2	
Poisson's Ratio, μ		0.45	
DRAINED PROPERTIES			
Drained Cohesion, c', psf	4-8*	0	
	8-18*	0	
	18-25*	0	
Angle of Internal Friction, ϕ', degrees	4-8*	24	
	8-18*	31	
	18-25*	22	
Elastic Modulus, E, psf	4-8*	180,000	
	8-18*	150,000	
	18-25*	252,000	

Notes:
1. Cohesive soils include Fat Clay, Lean Clay and Sandy Lean Clay.
2. Cohesionless soils include Silty Sand and Sandy Silt.

* Tunneling zone between depths of 4 to 24 feet (one bore diameter, but not less than 6 feet, above and below tunnel bore)

APPENDIX A

	Figure
Log of Borings	A-1 thru A-4
Symbols and Terms Used on Boring Logs	A-5

LOG OF BORING NO. GWL-1

PROJECT : Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NO. : 1140193701

LOCATION : N 13839966.13, E 3169135.67
See Plan of Borings (Figure 2)

COMPLETION DEPTH : 25.0 FT.

SURFACE ELEVATION : 25.12 FT.

DATE : 04-15-13

SAMPLER : Shelby Tube/Split Spoon
DRY AUGER : 0.0 TO 23.0 FT.
WET ROTARY : 23.0 TO 25.0 FT.

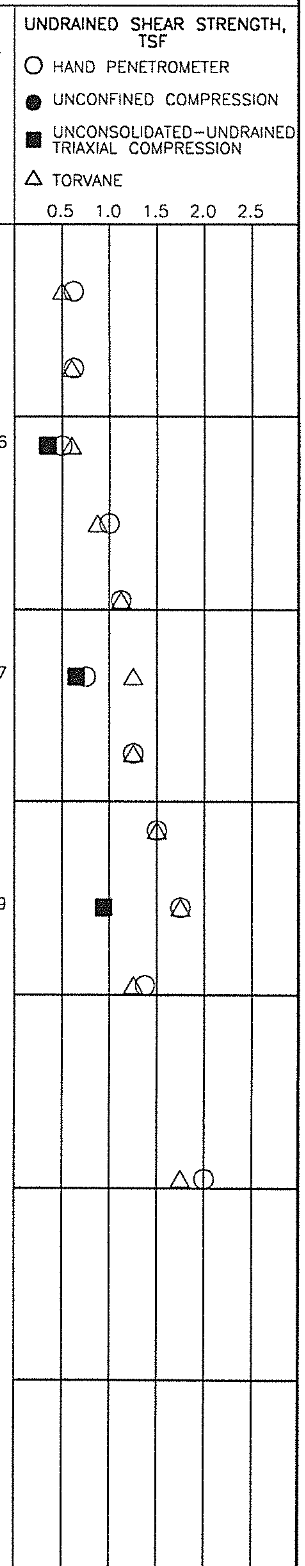
ELEVATION, FEET: 25.1 at DEPTH, FEET 0; 0.1 at DEPTH, FEET 25

DESCRIPTION OF MATERIAL

Stiff gray FAT CLAY (CH)
w/sand seams and ferrous nodules
-yellowish brown and gray 2'-18'
-medium stiff to stiff 4'-6'
-w/ferrous stains 4'-25'
-stiff to very stiff 6'-8'
-w/calcareous nodules 6'-18'
-very stiff 8'-10'
-stiff to very stiff 10'-12'
-very stiff 12'-16'
-stiff to very stiff 16'-18'
-w/vertical sand seams 18'-20'
-very stiff 18'-23'
-reddish brown and gray 18'-25'
-very stiff to hard 23'-25'

STANDARD PENETRATION TEST, BLOWS PER FOOT	PERCENT PASSING NO. 200 SIEVE	DRY UNIT WEIGHT, PCF	NATURAL MOISTURE CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
			23			
			26			
	92	86	34	87	31	56
			28			
			26			
	87	105	24	74	27	47
			26			
			24			
	85	101	22	64	25	39
			21			
			26			

UNDRAINED SHEAR STRENGTH, TSF



DEPTH TO WATER IN BORING :
∇: FREE WATER 1st ENCOUNTERED AT 23.0 FT. DURING DRILLING; AFTER 15.0 MIN. AT 21.0 FT.
HOLE OPEN TO 25.0 FT. AT END OF DRILLING.

Geotest Engineering, Inc.

FIGURE A-1

LOG OF BORING NO. GWL-2

PROJECT : Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NO. : 1140193701

LOCATION : N 13838999.05, E 3169181.89
See Plan of Borings (Figure 2)

COMPLETION DEPTH : 25.0 FT.

SURFACE ELEVATION : 22.88 FT.

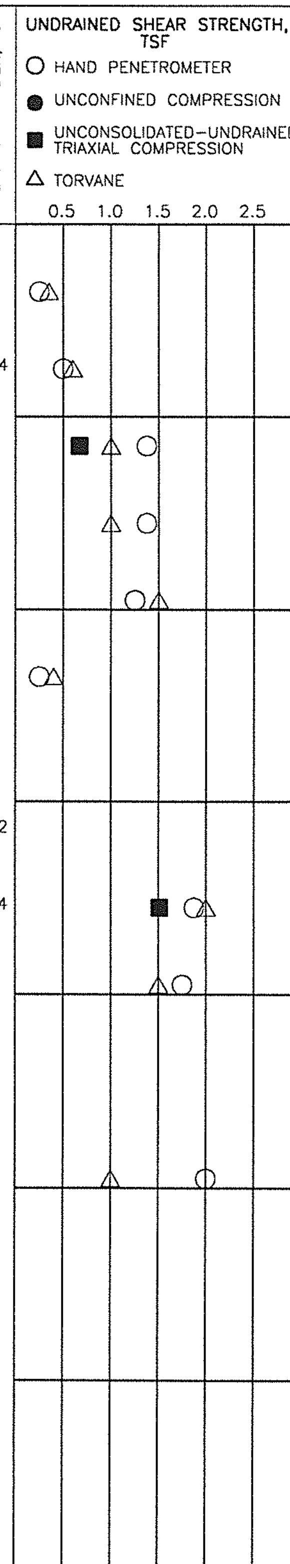
DATE : 04-16-13

SAMPLER : Shelby Tube/Split Spoon
DRY AUGER : 0.0 TO 12.0 FT.
WET ROTARY : 12.0 TO 25.0 FT.

ELEVATION, FEET	DEPTH, FEET	DESCRIPTION OF MATERIAL
22.9	0	Medium stiff brown LEAN CLAY (CL) w/grass roots and sand seams
20.9		Stiff gray and brown FAT CLAY (CH) w/ferrous nodules, ferrous stains and sand seams -stiff to very stiff, slickensided 4'-6'
16.9		Very stiff gray and yellowish brown LEAN CLAY (CL) w/sand, calcareous and ferrous nodules and silt seams -medium stiff very sandy clay 10'-12'
10.9		Medium dense reddish brown SILTY SAND (SM)
8.9		Reddish brown FAT CLAY (CH) w/calcareous nodules and ferrous stains -very stiff to hard w/sand seams 16'-18' -very stiff w/silt seams 18'-23'
-0.1		Very stiff to hard gray and yellowish brown SANDY LEAN CLAY (CL) w/ferrous nodules and ferrous stains
-2.1	25	

STANDARD PENETRATION TEST, BLOWS PER FOOT	PERCENT PASSING NO. 200 SIEVE	DRY UNIT WEIGHT, PCF	NATURAL MOISTURE CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
			23			
	88		26	70	26	44
		102	22			
			18			
			18			
			24			
13	41		24			
18	94		21	54	22	32
	99	105	24	70	26	44
			21			
			17			

UNDRAINED SHEAR STRENGTH, TSF



DEPTH TO WATER IN BORING :
∇: FREE WATER 1st ENCOUNTERED AT 12.0 FT. DURING DRILLING; AFTER 20.0 MIN. AT 7.3 FT.
HOLE OPEN TO 25.0 FT. AT END OF DRILLING.

Geotest Engineering, Inc.

FIGURE A-2

LOG OF BORING NO. GWL-3 (GWL-3P)

PROJECT : Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NO. : 1140193701

LOCATION : N 13838098.33, E 3169183.95 See Plan of Borings (Figure 2)

COMPLETION DEPTH : 50.0 FT.

SURFACE ELEVATION : 7.38 FT.

DATE : 04-16-13

SAMPLER : Shelby Tube/Split Spoon

DRY AUGER : 0.0 TO 12.0 FT.

WET ROTARY : 12.0 TO 50.0 FT.

ELEVATION, FEET	DEPTH, FEET	DESCRIPTION OF MATERIAL
7.4	0	FILL: stiff to very stiff brown sandy lean clay w/grass roots, gravel and calcareous and ferrous nodules -stiff 4'-6'
1.4		Medium stiff gray and yellowish brown SANDY LEAN CLAY (CL) w/ferrous nodules -soft to medium stiff 8'-10'
-2.6	10	Loose gray SANDY SILT (ML)
-5.6		Medium stiff yellowish brown and gray SANDY LEAN CLAY (CL) w/ferrous stains and sand seams -stiff 16'-18' -w/ferrous nodules 18'-20' -brown and red very sandy clay 20'-22'
-16.6		Very stiff to hard reddish brown and gray FAT CLAY (CH) w/calcareous nodules -slickensided 24'-26' -very stiff 26'-28' -w/gravel 28.5'-32'
-24.6		Stiff to very stiff reddish brown and gray SANDY LEAN CLAY (CL) w/sand seams -medium stiff to stiff 34'-36'
-27.6	35	

STANDARD PENETRATION TEST, BLOWS PER FOOT	PERCENT PASSING NO. 200 SIEVE	DRY UNIT WEIGHT, PCF	NATURAL MOISTURE CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
			20			
		102	22			
	65		18	44	20	24
			29			
			42			
5	58		19			
			30			
	54	109	19	25	16	9
			17			
			21			
			22			
9	56		22	44	20	24
	88	107	21	54	22	32
			24			
33			21			
	95	106	21	50	21	29
			20			

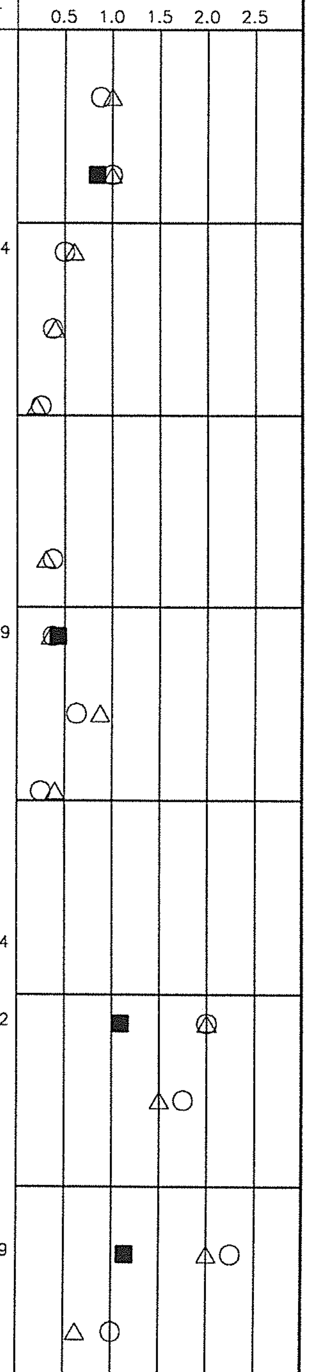
UNDRAINED SHEAR STRENGTH, TSF

○ HAND PENETROMETER

● UNCONFINED COMPRESSION

■ UNCONSOLIDATED-UNDRAINED TRIAXIAL COMPRESSION

△ TORVANE



DEPTH TO WATER IN BORING :

▽: FREE WATER 1st ENCOUNTERED AT 10.0 FT. DURING DRILLING; AFTER 20.0 MIN. AT 5.3 FT.
HOLE OPEN TO 50.0 FT. AT END OF DRILLING.

Continued on Figure A-3a

Geotest Engineering, Inc.

LOG OF BORING NO. GWL-3 (GWL-3P) Cont'd

PROJECT : Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NO. : 1140193701

LOCATION : N 13838098.33, E 3169183.95 See Plan of Borings (Figure 2)

COMPLETION DEPTH : 50.0 FT.

SURFACE ELEVATION : 7.38 FT.

DATE : 04-16-13

SAMPLER : Shelby Tube/Split Spoon
DRY AUGER : 0.0 TO 12.0 FT.
WET ROTARY : 12.0 TO 50.0 FT.

UNDRAINED SHEAR STRENGTH, TSF: ○ HAND PENETROMETER; ● UNCONFINED COMPRESSION; ■ UNCONSOLIDATED-UNDRAINED TRIAXIAL COMPRESSION; △ TORVANE. Scale: 0.5 1.0 1.5 2.0 2.5

ELEVATION, FEET	DEPTH, FEET	DESCRIPTION OF MATERIAL	STANDARD PENETRATION TEST, BLOWS PER FOOT	PERCENT PASSING NO. 200 SIEVE	DRY UNIT WEIGHT, PCF	NATURAL MOISTURE CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
-27.6	35	Stiff to very stiff reddish brown and gray SANDY LEAN CLAY (CL) w/sand seams				21			
-29.1		Dense to very dense gray and reddish brown SANDY SILT (ML) -w/calcareous nodules 36.5'-42' -w/clay seams 40.5'-42'	61			21			
	40		49	70		25			
			65			22			
	45		76/3.0"			23			
-42.6	50		100/5.0"			18			
	55								
	60								
	65								
	70								

DEPTH TO WATER IN BORING :
∇: FREE WATER 1st ENCOUNTERED AT 10.0 FT. DURING DRILLING; AFTER 20.0 MIN. AT 5.3 FT.
HOLE OPEN TO 50.0 FT. AT END OF DRILLING.

Geotest Engineering, Inc.

FIGURE A-3a

LOG OF BORING NO. GWL-4

PROJECT : Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NO. : 1140193701

LOCATION : N 13837935.00, E 3169175.14
See Plan of Borings (Figure 2)

COMPLETION DEPTH : 50.0 FT.

SURFACE ELEVATION : 6.79 FT.

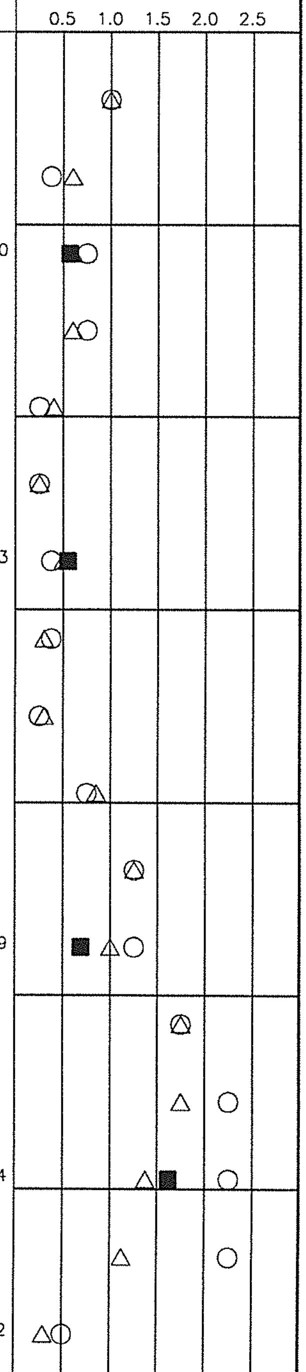
DATE : 04-15-13

SAMPLER : Shelby Tube/Split Spoon
DRY AUGER : 0.0 TO 12.0 FT.
WET ROTARY : 12.0 TO 50.0 FT.

ELEVATION, FEET	DEPTH, FEET	DESCRIPTION OF MATERIAL
6.8	0	FILL: very stiff brown sandy lean clay -w/grass roots 0'-2' -medium stiff to stiff 2'-4' -medium stiff to stiff yellowish brown, gray fat clay w/calcareous and ferrous nodules 2'-10' -w/ferrous stains 4'-8' -gray and reddish brown 6'-8' -gray 8'-10'
-3.2	10	Medium stiff gray SANDY LEAN CLAY (CL) w/sand seams -medium stiff to stiff 12'-14' -w/ferrous nodules 14'-16' -w/clay seams 14'-18' -yellowish brown and gray 16'-18'
-11.2	18	Stiff yellowish brown and gray FAT CLAY (CH) w/calcareous and ferrous nodules, sand seams and ferrous stains -very stiff 20'-22' -stiff to very stiff, slickensided 22'-24' -very stiff 24'-26'
-19.2	26	Very stiff to hard gray and reddish brown LEAN CLAY (CL) w/sand seams -w/calcareous nodules 30'-32' -medium stiff to stiff 32'-34'
-27.2	34	Very dense gray and reddish brown SANDY SILT (ML)
-28.2	35	

STANDARD PENETRATION TEST, BLOWS PER FOOT	PERCENT PASSING NO. 200 SIEVE	DRY UNIT WEIGHT, PCF	NATURAL MOISTURE CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
			14			
			20			
	86	107	22	51	21	30
			21			
			30			
			18			
	69	105	20	28	15	13
			23			
			23			
			24			
			21			
	88	107	21	63	24	39
			23			
			21			
	97	116	17	43	19	24
			20			
	88		22	30	18	12

UNDRAINED SHEAR STRENGTH, TSF
○ HAND PENETROMETER
● UNCONFINED COMPRESSION
■ UNCONSOLIDATED-UNDRAINED TRIAXIAL COMPRESSION
△ TORVANE



DEPTH TO WATER IN BORING :
∇: FREE WATER 1st ENCOUNTERED AT 11.0 FT. DURING DRILLING; AFTER 20.0 MIN. AT 7.7 FT.
HOLE OPEN TO 50.0 FT. AT END OF DRILLING.

Continued on Figure A-4a

Geotest Engineering, Inc.

LOG OF BORING NO. GWL-4 Cont'd

PROJECT : Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NO. : 1140193701

LOCATION : N 13837935.00, E 3169175.14 See Plan of Borings (Figure 2)

COMPLETION DEPTH : 50.0 FT.

SURFACE ELEVATION : 6.79 FT.

DATE : 04-15-13

SAMPLER : Shelby Tube/Split Spoon

DRY AUGER : 0.0 TO 12.0 FT.

WET ROTARY : 12.0 TO 50.0 FT.

UNDRAINED SHEAR STRENGTH, TSF: O HAND PENETROMETER; ● UNCONFINED COMPRESSION; ■ UNCONSOLIDATED-UNDRAINED TRIAXIAL COMPRESSION; △ TORVANE (scale 0.5 1.0 1.5 2.0 2.5)

ELEVATION, FEET	DEPTH, FEET	DESCRIPTION OF MATERIAL	STANDARD PENETRATION TEST, BLOWS PER FOOT	PERCENT PASSING NO. 200 SIEVE	DRY UNIT WEIGHT, PCF	NATURAL MOISTURE CONTENT, %	LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %
-28.2	35	Very dense gray and reddish brown SANDY SILT (ML)	68	69		22			
			75			25			
-31.2		Very dense reddish brown SILTY SAND (SM)							
	40		51/7.0"			26			
		-dense 40.5'-42'	43			24			
		-w/gravel and clay seams 43.5'-50'							
	45		77			25			
-43.2	50		91/5.5"			21			
	55								
	60								
	65								
	70								

DEPTH TO WATER IN BORING :
∇: FREE WATER 1st ENCOUNTERED AT 11.0 FT. DURING DRILLING; AFTER 20.0 MIN. AT 7.7 FT.
HOLE OPEN TO 50.0 FT. AT END OF DRILLING.

Geotest Engineering, Inc.

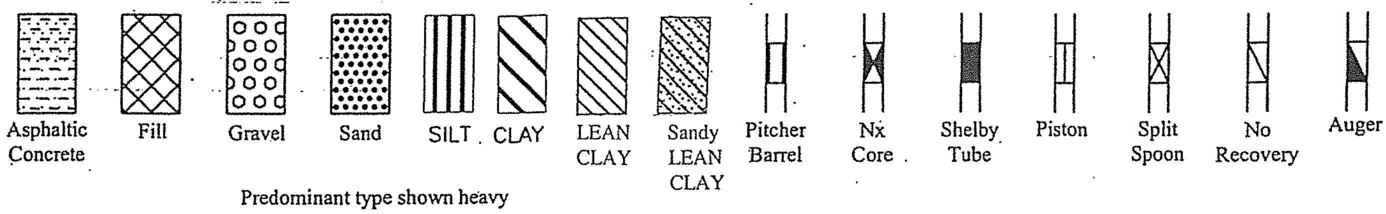
FIGURE A-4a

Job No. 1140193701

SYMBOLS AND TERMS USED ON BORING LOGS

SOIL TYPES
(SHOWN IN SYMBOL COLUMN)

SAMPLER TYPES
(SHOWN IN SAMPLES COLUMN)



Predominant type shown heavy

TERMS DESCRIBING CONSISTENCY OR CONDITION

Basic Soil Type	Density or Consistency	Standard Penetration Resistance, (1) Blows/ft.	Unconfined Compressive Strength (q_u), (2) Tons/sq. ft.
Cohesionless	Very loose	Less than 4	Not applicable
	Loose	4 to <10	Not applicable
	Medium dense	10 to <30	Not applicable
	Dense	30 to <50	Not applicable
	Very dense	50 or greater	Not applicable
Cohesive	Very soft	Less than 2	Less than 0.25
	Soft	2 to <4	0.25 to <0.5
	Firm/Medium stiff	4 to <8	0.5 to <1.0
	Stiff	8 to <15	1.0 to <2.0
	Very stiff	15 to <30	2.0 to <4.0
	Hard	30 or greater	4 or greater

(1) Number of blows from 140-lb. weight falling 30-in. to drive 2-in. OD, 1-3/8-in. ID, split barrel sampler (ASTM D1586)

(2) q_u may also be approximated using a pocket penetrometer

TERMS CHARACTERIZING SOIL STRUCTURE

Parting: -paper thin in size   Seam: -1/8" to 3" thick   Layer: -greater than 3"

Slickensided	- having inclined planes of weakness that are slick and glossy in appearance.
Fissured	- containing shrinkage cracks, frequently filled with fine sand or silt; usually more or less vertical.
Laminated	- composed of thin layers of varying color and texture.
Interbedded	- composed of alternate layers of different soil types.
Calcareous	- containing appreciable quantities of calcium carbonate.
Well graded	- having wide range in grain sizes and substantial amounts of all intermediate particle sizes.
Poorly graded	- predominantly of one grain size, or having a range of sizes with some intermediate size missing.
Flocculated	- pertaining to cohesive soils that exhibit a loose knit or flakey structure.

APPENDIX B

	Figure
Summary of Laboratory Test Results	B-1 thru B-4
Grain Size Distribution Curves	B-5 and B-6

SUMMARY OF LABORATORY TEST RESULTS

GEOTEST ENGINEERING, INC.

PROJECT NAME: Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NUMBER: 1140193701

BORING NO.	SAMPLE				SPT (blows/ft.)	WATER CONTENT (%)	DRY DENSITY (pcf)	ATTERBERG LIMITS			PASSING NO. 200 SIEVE (%)	UNCONFINED COMPRESSION TEST	TRIAXIAL COMPRESSION TEST (U-U)		TORVANE	POCKET PENE-TROMETER	TYPE OF MATERIAL
	No.	Depth (ft.) Top	Depth (ft.) Bottom	Type				LL	PL	PI		Shear Strength (tsf)	Shear Strength (tsf)	Conf. Press. (tsf)	Shear Strength (tsf)	Shear Strength (tsf)	
GWL-1	1	0.0	2.0	UD		23									0.50	0.63	Fat Clay
	2	2.0	4.0	UD		26									0.60	0.63	Fat Clay
	3	4.0	6.0	UD		34	86	87	31	56	92		0.35	0.43	0.60	0.50	Fat Clay
	4	6.0	8.0	UD		28									0.88	1.00	Fat Clay
	5	8.0	10.0	UD		26									1.13	1.13	Fat Clay
	6	10.0	12.0	UD		24	105	74	27	47	87		0.65	0.86	1.25	0.75	Fat Clay
	7	12.0	14.0	UD		26									1.25	1.25	Fat Clay
	8	14.0	16.0	UD		24									1.50	1.50	Fat Clay
	9	16.0	18.0	UD		22	101	64	25	39	85		0.94	1.30	1.75	1.75	Fat Clay
	10	18.0	20.0	UD		21									1.25	1.38	Fat Clay
	11	23.0	25.0	UD		26									1.75	2.00	Fat Clay

LEGEND:
UD = UNDISTURBED SAMPLE, EXTRUDED IN FIELD
SS = SPLIT SPOON SAMPLE
AG = AUGER CUTTINGS
PB = PITCHER BARREL SAMPLE
Nx = Nx-DOUBBLE BARREL SAMPLE

SPT = Standard Penetration Test
LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

FIGURE B-1

SUMMARY OF LABORATORY TEST RESULTS

GEOTEST ENGINEERING, INC.

PROJECT NAME: Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NUMBER: 1140193701

BORING NO.	SAMPLE No.	Depth (ft.) Top	Depth (ft.) Bottom	Type	SPT (blows/ft.)	WATER CONTENT (%)	DRY DENSITY (pcf)	ATTERBERG LIMITS LL	PL	PI	PASSING NO. 200 SIEVE (%)	UNCONFINED COMPRESSION TEST Shear Strength (tsf)	TRIAXIAL COMPRESSION TEST (U-U) Shear Strength (tsf)	Conf. Press. (tsf)	TORVANE Shear Strength (tsf)	POCKET PENE-TROMETER Shear Strength (tsf)	TYPE OF MATERIAL
GWL-2	1	0.0	2.0	UD		23									0.35	0.25	Lean Clay
	2	2.0	4.0	UD		26		70	26	44	88				0.60	0.50	Fat Clay
	3	4.0	6.0	UD		22	102						0.67	0.43	1.00	1.38	Fat Clay
	4	6.0	8.0	UD		18									1.00	1.38	Lean Clay
	5	8.0	10.0	UD		18									1.50	1.25	Lean Clay
	6	10.0	12.0	UD		24									0.40	0.25	Lean Clay
	7	12.5	14.0	SS	13	24					41						Silty Sand
	8	14.5	16.0	SS	18	21		54	22	32	94						Fat Clay
	9	16.0	18.0	UD		24	105	70	26	44	99		1.51	1.30	2.00	1.88	Fat Clay
	10	18.0	20.0	UD		21									1.50	1.75	Fat Clay
	11	23.0	25.0	UD		17									1.00	2.00	Sandy Lean Clay

LEGEND:
UD = UNDISTURBED SAMPLE, EXTRUDED IN FIELD
SS = SPLIT SPOON SAMPLE
AG = AUGER CUTTINGS
PB = PITCHER BARREL SAMPLE
Nx = Nx-DOUBBLE BARREL SAMPLE

SPT = Standard Penetration Test
LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

FIGURE B-2

SUMMARY OF LABORATORY TEST RESULTS

GEOTEST ENGINEERING, INC.

PROJECT NAME: Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NUMBER: 1140193701

BORING NO.	SAMPLE				SPT (blows/ft.)	WATER CONTENT (%)	DRY DENSITY (pcf)	ATTERBERG LIMITS			PASSING NO. 200 SIEVE (%)	UNCONFINED COMPRESSION TEST	TRIAXIAL COMPRESSION TEST (U-U)		TORVANE	POCKET PENE-TROMETER	TYPE OF MATERIAL
	No.	Depth (ft.) Top	Depth (ft.) Bottom	Type				LL	PL	PI		Shear Strength (tsf)	Shear Strength (tsf)	Conf. Press. (tsf)	Shear Strength (tsf)	Shear Strength (tsf)	
GWL-3 (GWL-3P)	1	0.0	2.0	UD		20									1.00	0.88	Fill
	2	2.0	4.0	UD		22	102						0.84	0.29	1.00	1.00	Fill
	3	4.0	6.0	UD		18		44	20	24	65				0.60	0.50	Fill
	4	6.0	8.0	UD		29									0.40	0.38	Sandy Lean Clay
	5	8.0	10.0	UD		42									0.20	0.25	Sandy Lean Clay
	6	10.5	12.0	SS	5	19					58						Sandy Silt
	7	12.0	14.0	UD		30									0.30	0.38	Sandy Lean Clay
	8	14.0	16.0	UD		19	109	25	16	9	54		0.43	1.15	0.35	0.38	Sandy Lean Clay
	9	16.0	18.0	UD		17									0.88	0.63	Sandy Lean Clay
	10	18.0	20.0	UD		21									0.40	0.25	Sandy Lean Clay
	11	20.0	22.0	UD		22											Sandy Lean Clay
	12	22.5	24.0	SS	9	22		44	20	24	56						Sandy Lean Clay
	13	24.0	26.0	UD		21	107	54	22	32	88		1.09	1.87	2.00	2.00	Fat Clay
	14	26.0	28.0	UD		24									1.50	1.75	Fat Clay
	15	28.5	30.0	SS	33	21											Fat Clay
	16	30.0	32.0	UD		21	106	50	21	29	95		1.14	2.30	2.00	2.25	Fat Clay
	17	32.0	34.0	UD		20									0.63	1.00	Sandy Lean Clay
	18	34.0	36.0	UD		21									0.35	0.63	Sandy Lean Clay
	19	36.5	38.0	SS	61	21											Sandy Silt
	20	38.5	40.0	SS	49	25					70						Sandy Silt
	21	40.5	42.0	SS	65	22											Sandy Silt

LEGEND:
UD = UNDISTURBED SAMPLE, EXTRUDED IN FIELD
SS = SPLIT SPOON SAMPLE
AG = AUGER CUTTINGS
PB = PITCHER BARREL SAMPLE
Nx = Nx-DOUBBLE BARREL SAMPLE

SPT = Standard Penetration Test
LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

FIGURE B-3

SUMMARY OF LABORATORY TEST RESULTS

GEOTEST ENGINEERING, INC.

PROJECT NAME: Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NUMBER: 1140193701

BORING NO.	SAMPLE				SPT (blows/ft.)	WATER CONTENT (%)	DRY DENSITY (pcf)	ATTERBERG LIMITS			PASSING NO. 200 SIEVE (%)	UNCONFINED COMPRESSION TEST	TRIAXIAL COMPRESSION TEST (U-U)		TORVANE	POCKET PENE-TROMETER	TYPE OF MATERIAL
	No.	Depth (ft.) Top	Depth (ft.) Bottom	Type				LL	PL	PI		Shear Strength (tsf)	Shear Strength (tsf)	Conf. Press. (tsf)	Shear Strength (tsf)	Shear Strength (tsf)	
GWL-3 (GWL-3P)	22	43.5	45.0	SS	76/3.0"	23											Sandy Silt
	23	48.5	50.0	SS	100/5.0"	18											Sandy Silt

LEGEND:
UD = UNDISTURBED SAMPLE, EXTRUDED IN FIELD
SS = SPLIT SPOON SAMPLE
AG = AUGER CUTTINGS
PB = PITCHER BARREL SAMPLE
Nx = Nx-DOUBBLE BARREL SAMPLE

SPT = Standard Penetration Test
LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

FIGURE B-3a

SUMMARY OF LABORATORY TEST RESULTS

GEOTEST ENGINEERING, INC.

PROJECT NAME: Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NUMBER: 1140193701

BORING NO.	SAMPLE				SPT (blows/ft.)	WATER CONTENT (%)	DRY DENSITY (pcf)	ATTERBERG LIMITS			PASSING NO. 200 SIEVE (%)	UNCONFINED COMPRESSION TEST	TRIAXIAL COMPRESSION TEST (U-U)		TORVANE	POCKET PENE-TROMETER	TYPE OF MATERIAL
	No.	Depth (ft.) Top	Depth (ft.) Bottom	Type				LL	PL	PI		Shear Strength (tsf)	Shear Strength (tsf)	Conf. Press. (tsf)	Shear Strength (tsf)	Shear Strength (tsf)	
GWL-4	1	0.0	2.0	UD		14									1.00	1.00	Fill
	2	2.0	4.0	UD		20									0.60	0.38	Fill
	3	4.0	6.0	UD		22	107	51	21	30	86		0.57	0.43	0.60	0.75	Fill
	4	6.0	8.0	UD		21									0.60	0.75	Fill
	5	8.0	10.0	UD		30									0.40	0.25	Fill
	6	10.0	12.0	UD		18									0.25	0.25	Sandy Lean Clay
	7	12.0	14.0	UD		20	105	28	15	13	69		0.55	1.01	0.50	0.38	Sandy Lean Clay
	8	14.0	16.0	UD		23									0.30	0.38	Sandy Lean Clay
	9	16.0	18.0	UD		23									0.30	0.25	Sandy Lean Clay
	10	18.0	20.0	UD		24									0.85	0.75	Fat Clay
	11	20.0	22.0	UD		21									1.25	1.25	Fat Clay
	12	22.0	24.0	UD		21	107	63	24	39	88		0.69	1.73	1.00	1.25	Fat Clay
	13	24.0	26.0	UD		23									1.75	1.75	Fat Clay
	14	26.0	28.0	UD		21									1.75	2.25	Lean Clay
	15	28.0	30.0	UD		17	116	43	19	24	97		1.62	2.16	1.38	2.25	Lean Clay
	16	30.0	32.0	UD		20									1.13	2.25	Lean Clay
	17	32.0	34.0	UD		22		30	18	12	88				0.30	0.50	Lean Clay
	18	34.5	36.0	SS	68	22					69						Sandy Silt
	19	36.5	38.0	SS	75	25											Sandy Silt
	20	38.5	40.0	SS	51/7.0"	26											Silty Sand
	21	40.0	41.5	SS	43	24											Silty Sand

LEGEND:
UD = UNDISTURBED SAMPLE, EXTRUDED IN FIELD
SS = SPLIT SPOON SAMPLE
AG = AUGER CUTTINGS
PB = PITCHER BARREL SAMPLE
Nx = Nx-DOUBBLE BARREL SAMPLE

SPT = Standard Penetration Test
LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

FIGURE B-4

SUMMARY OF LABORATORY TEST RESULTS

GEOTEST ENGINEERING, INC.

PROJECT NAME: Surface Water Transmission Program; 84-inch Interconnect at East Water Purification Plant (EWPP) WBS No. S-000900-0132-3; Houston, Texas

PROJECT NUMBER: 1140193701

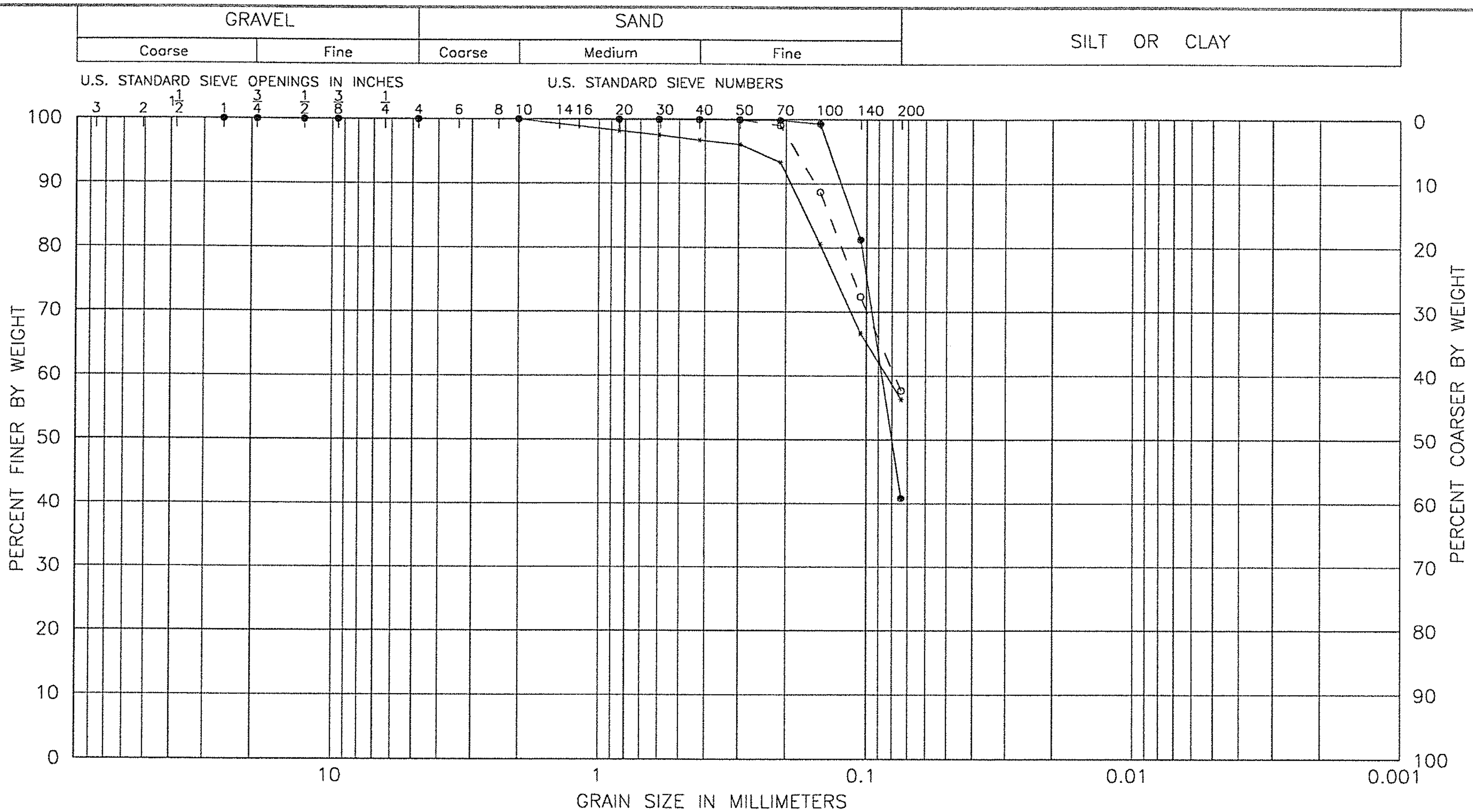
BORING NO.	SAMPLE				SPT (blows/ft.)	WATER CONTENT (%)	DRY DENSITY (pcf)	ATTERBERG LIMITS			PASSING NO. 200 SIEVE (%)	UNCONFINED COMPRESSION TEST	TRIAXIAL COMPRESSION TEST (U-U)		TORVANE	POCKET PENE-TROMETER	TYPE OF MATERIAL
	No.	Depth (ft.) Top	Depth (ft.) Bottom	Type				LL	PL	PI		Shear Strength (tsf)	Shear Strength (tsf)	Conf. Press. (tsf)	Shear Strength (tsf)	Shear Strength (tsf)	
GWL-4	22	43.5	45.0	SS	77	25											Silty Sand
	23	48.5	50.0	SS	91/5.5"	21											Silty Sand

LEGEND:
UD = UNDISTURBED SAMPLE, EXTRUDED IN FIELD
SS = SPLIT SPOON SAMPLE
AG = AUGER CUTTINGS
PB = PITCHER BARREL SAMPLE
Nx = Nx-DOUBBLE BARREL SAMPLE

SPT = Standard Penetration Test
LL = Liquid Limit
PL = Plastic Limit
PI = Plasticity Index

FIGURE B-4a

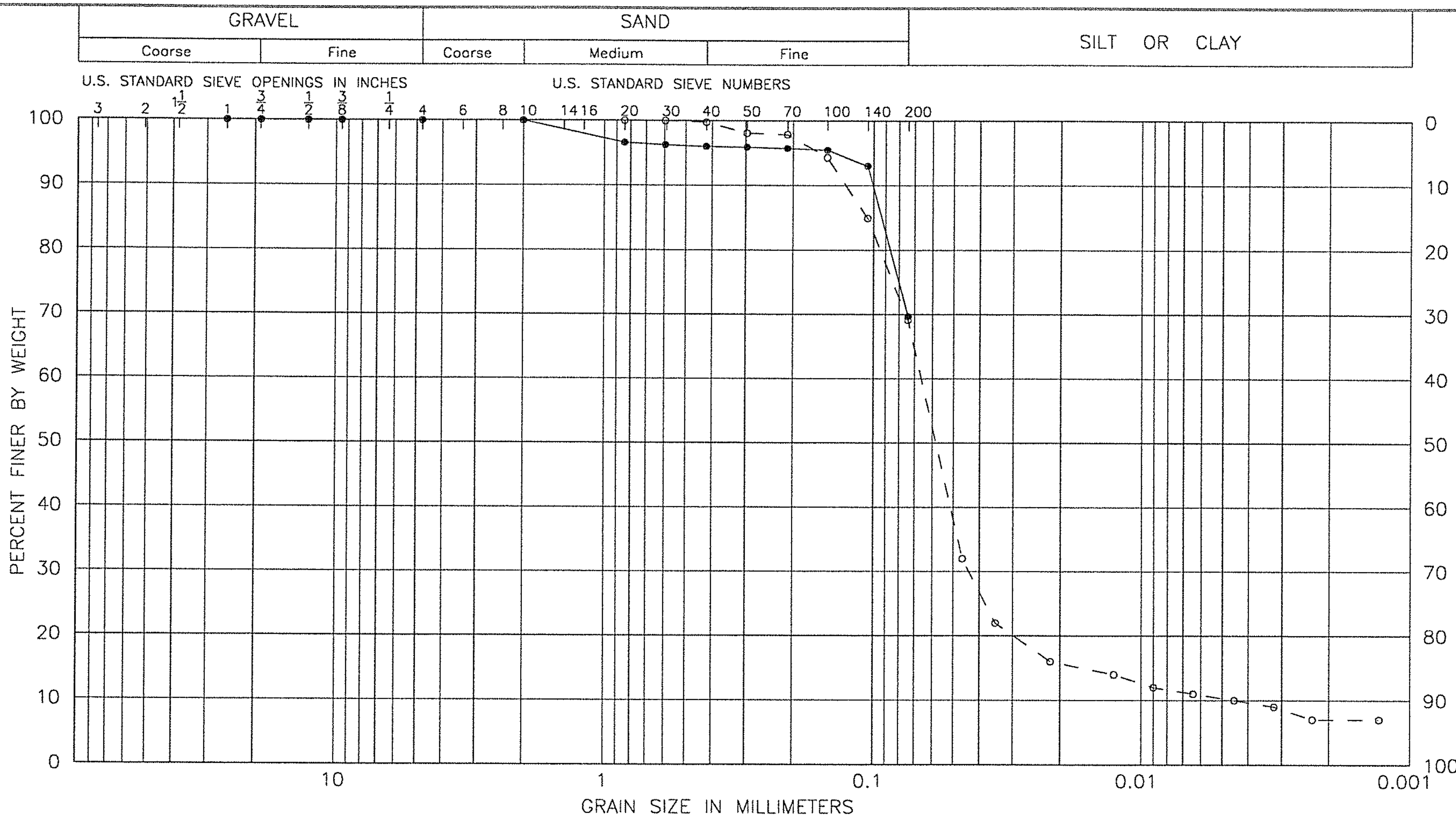
Job No. 1140193701



LEGEND	BORING NO.	SAMPLE NO.	DEPTH FT.	SAMPLE DESCRIPTION
●—●—●	GWL-2	S-7	12.5-14.0	Reddish brown silty sand
○—○—○	GWL-3	S-6	10.5-12.0	Gray sandy silt
×—×—×	GWL-3	S-12	22.5-24.0	Brown and red very sandy clay

GRAIN SIZE DISTRIBUTION CURVES

Job No. 1140193701



LEGEND	BORING NO.	SAMPLE NO.	DEPTH FT.	SAMPLE DESCRIPTION
●-●-●-●	GWL-3	S-20	38.5-40.0	Gray and reddish brown sandy silt
○-○-○-○	GWL-4	S-18	34.5-36.0	Gray and reddish brown sandy silt

GRAIN SIZE DISTRIBUTION CURVES

Geotest Engineering, Inc.

FIGURE B-6

APPENDIX C

Figure

Piezometer Installation Report C-1

Piezometer Abandonment Report C-2

Job No. 1140193701

PIEZOMETER INSTALLATION REPORT

PROJECT NAME: Surface Water Transmission Program; 84-inch Waterline Interconnect at East Water Purification Pant (EWPP)		PIEZOMETER NUMBER: GWL-3P
GEOTECHNICAL CONSULTANT GEOTEST ENGINEERING, INC.	DESIGN CONSULTANT LAN	CITY OF HOUSTON,TEXAS

COMPLETION DATE 4-16-13

DRY AUGERED 0 TO 12.0 FT

WASH BORED 12.0 TO 50.0 FT

DRILLING FLUID: WATER

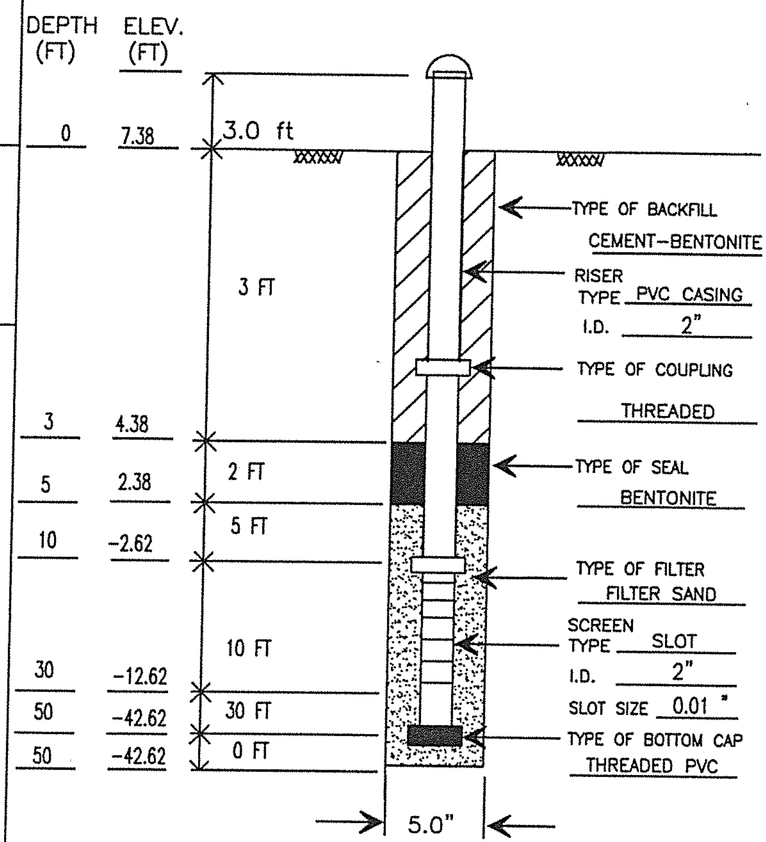
DEVELOPMENT DATE: 12-4-12

METHOD OF DEVELOPMENT:

BAILING

WATER LEVEL READINGS:

DATE	DEPTH, FT (TOG)	ELEVATION, FT
4-17-13	4.0	3.38
5-16-13	3.5	3.88



(NOT TO SCALE)

REMARKS:

NOTES:
1. DIMENSIONS NOMINAL UNLESS OTHERWISE NOTED
2. TOG = TOP OF GROUND

DRILLED BY: JM	STARTED: 4-16-13	Northing: 13838098.33 Easting: 3169183.95
LOGGED BY: TM	COMPLETED: 4-16-13	GROUND LEVEL (MSL): 7.38
CHECKED BY: NK	APPROVED BY: MB	SHEET 1 OF 1

STATE OF TEXAS PLUGGING REPORT for Tracking #90919

Owner:	City of Houston Geotech Dept	Owner Well #:	1
Address:	611 Walker, Floor 14 Houston , TX 77002	Grid #:	65-23-1
Well Location:	2300 Federal Rd Houston , TX 77051	Latitude:	29° 44' 44" N
Well County:	Harris	Longitude:	095° 12' 50" W
		GPS Brand Used:	No Data
Well Type:	Monitor		

HISTORICAL DATA ON WELL TO BE PLUGGED

Original Well Driller:	Eddie VanAntwerp
Driller's License Number of Original Well Driller:	2903M
Date Well Drilled:	4/16/2013
Well Report Tracking Number:	2300FR
Diameter of Borehole:	6 inches
Total Depth of Borehole:	50 feet

Date Well Plugged:	11/11/2013
Person Actually Performing Plugging Operation:	Eddie VanAntwerp
License Number of Plugging Operator:	2903
Plugging Method:	Tremmie pipe cement from bottom to top.
Plugging Variance #:	No Data
Casing Left Data:	1st Interval: 2 inches diameter, From 0 ft to 50 ft 2nd Interval: No Data 3rd Interval: No Data
Cement/Bentonite Plugs Placed in Well:	1st Interval: From 0 ft to 50 ft; Sack(s)/type of cement used: 2 2nd Interval: No Data 3rd Interval: No Data 4th Interval: No Data 5th Interval: No Data

Certification Data:	The plug installer certified that the plug installer plugged this well (or the well was plugged under the plug installer's direct supervision) and that each and all of the statements herein are true and correct. The plug installer understood that failure to complete the required items will result in the log(s) being returned for completion and resubmittal.
Company Information:	Van and Sons Drilling Service 319 John Alber Houston , TX 77076
Plug Installer License Number:	2903

FIGURE C-2a

Licensed Plug Installer Signature:	**Eddie VanAntwerp**
Registered Plug Installer Apprentice Signature:	**Jose Luna**
Apprentice Registration Number:	**No Data**
Plugging Method Comments:	**No Data**

Please include the plugging report's tracking number (Tracking #90919) on your written request.

Texas Department of Licensing & Regulation
P.O. Box 12157
Austin, TX 78711
(512) 463-7880

Attn:
Tiffany

3 pgs

Attention Owner:
Confidentiality Privilege Notice on reverse side of owner's copy.

Texas Department of Licensing and Regulation

Water Well Driller/Pump Installer Program
P.O. Box 12157 Austin, Texas 78711 (512) 463-7880 FAX (512) 463-8616
Toll free (800) 803-9202
Email address: water.well@license.state.tx.us

This form must be completed and filed with the department and owner within 60 days upon completion of the well.

WELL REPORT

1) OWNER — A. WELL IDENTIFICATION AND LOCATION DATA

Name	Address	City	State	Zip
City of Houston Geotechnical Dept	611 Walker Floor 14	Houston	Tx	77002

2) WELL LOCATION

County	Physical Address	City	State	Zip
Harris	2300 Federal Rd	Houston	Tx	77051

3) Type of Work
☒ New Well ☐ Reconditioning ☐ Replacement ☐ Deepening

Lat. ° ' " Long. ° ' " Grid # 65-23-1

4) Proposed Use (check) ☒ Monitor ☐ Environmental Soil Boring ☐ Domestic ☐ Industrial ☐ Irrigation ☐ Injection ☐ Public Supply ☐ De-watering ☐ Testwell ☐ Rig Supply ☐ Stock or Livestock
If Public Supply, were plans approved? ☐ Yes ☐ No

5) N↑

6) Drilling Date
Started 4/16/13
Completed 4/16/13

Diameter of Hole

Dia. (in)	From (ft)	To (ft)
	Surface	
6	0	50

7) Drilling Method (check)
☐ Driven ☐ Air Rotary ☒ Mud Rotary ☐ Bored ☐ Air Hammer ☐ Cable Tool ☐ Jetted ☐ Hollow Stem Auger ☐ Reverse Circulation ☐ Other

From (ft)	To (ft)	Description and color of formation material

(Use reverse side of Well Owner's copy, if necessary)

8) Borehole Completion ☐ Open Hole ☐ Straight Wall ☐ Under-reamed ☐ Gravel Packed ☐ Other
Gravel Packed interval from ft. to ft. Size

Casing, Blank Pipe, and Well Screen Data

Dia. (in.)	New Or Used	Steel, Plastic, etc. Perf., Slotted, etc. Screen Mfg., if commercial	Setting (ft) From	To	Gage Casing Screen
2	n	Sch 40 PVC Riser	0	40	
2	n	Sch 40 PVC Screen	40	50	.010

9) Annular Seal Data: i.e. *(from 0 ft to 100 ft #sacks & material 13 cement)*
from 0 ft. to 36 ft. #sacks & material 2 cement
from 36 ft. to 38 ft. #sacks & material .5 bentonite
from ft. to ft. #sacks & material
Method Used
Distance to septic field or other concentrated contamination na ft.
Distance to Property Line na ft Method Verified:

10) Surface Completion (If steel cased, leave blank)
☐ Surface Slab Installed ☐ Surface Sleeve Installed ☐ Pitless Adapter Used ☒ Alternative Procedure Used

11) Water Level
Static level na ft. Date / /
Artesian Flow gpm

12) Packers

Type	Depth	Type	Depth
20/40	38-50		

13) Plugged ☐ Well plugged within 48 hours
Casing left in well: Cement/Bentonite placed in well:

From (ft)	To (ft)	From (ft)	To (ft)	Material used & # Sacks

14) Type Pump
☐ Turbine ☐ Jet ☐ Submersible ☐ Cylinder ☐ Other
Depth to pump bowls, cylinder, jet, etc., ft.

15) Water Test
Type test ☐ Pump ☐ Bailer ☐ Jetted ☐ Estimated
Yield: na gpm with ft. drawdown after hrs.

16) Water Quality
Type of water: Depth of Strata: Was a chemical analysis made? ☐ Yes ☒ No
Did you knowingly penetrate a strata which contains undesirable constituents? ☐ Yes ☒ No If yes, Continue:
Check One: ☐ Naturally poor-quality groundwater – type ☐ Hydrocarbons (i.e. gas, oil, etc.) ☐ Hazardous material/waste contamination encountered ☐ Other (describe)

☐ *I certify that while drilling, deepening, or otherwise altering the above described well, undesirable water or constituents was encountered and the landowner was informed that such well must be completed or plugged in such a manner as to avoid injury or pollution.*

Company or Individual's Name (type or print) Van and Sons Drilling Service, Inc Lic. No. 2903M
Address 319 John Alber City Houston State Tx Zip 77076
Signature [signature] 4/26/13 Signature / /
Licensed Driller/Pump Installer Date Apprentice Date

TDLR FORM 001WWD / 9-03 Copies to TDLR - Owner - Driller/Pump Installer Form provided by Forms On-A-Disk • (214) 340-9429 • FormsOnADI FIGURE C-2c

APPENDIX D

	Figure
Example Calculations of Bracing Pressures	D-1 thru D-3

APPENDIX D

Design Example 1

Given: Determine the bracing pressures by using the formulas provided in Figure 5.1 assuming the following:

- Assume excavation is 20-ft deep.
- Assume cohesive soils are between the ground surface and the depth of 20-ft.
- Assume a surcharge load at the ground surface (q) of 500 psf.
- Assume groundwater level is at the ground surface.
- Wet unit weight is 123 pcf.
- Submerged unit weight is 61 pcf.

Calculation Procedure: From the formulas provided in Figure 5.1 bracing pressures are computed as follows:

$\mathbf{P_1}$ = 0.3 x 61 pcf x 20-ft = 366 psf

$\mathbf{P_w}$ = 62.4 pcf x 20-ft = 1,248 psf

$\mathbf{P_q}$ = 500psf x 0.5 = 250 psf

Bracing pressure at the ground surface = $\mathbf{P_q}$ = 250 psf

Bracing pressure at depths of H/4 (5-ft) = $\mathbf{P_1} + \mathbf{P_w} + \mathbf{P_q}$ = 366+62.4x5+250 = 928 psf

Bracing pressure at depth of 3H/4 (15-ft) = $\mathbf{P_1} + \mathbf{P_w} + \mathbf{P_q}$ = 366+62.4x15+250 = 1,552 psf

Bracing pressure at depth of 20-ft = $\mathbf{P_q} + \mathbf{P_w}$ = 1,248+250 = 1,498 psf

APPENDIX D
(cont'd)

Design Example 2

Given: Determine the bracing pressures by using the formulas provided in Figure 5.2 assuming the following:

- Assume excavation is 20-ft deep.
- Assume cohesive soils are between the ground surface and the depth of 20-ft.
- Assume a surcharge load at the ground surface (q) of 500 psf.
- Assume groundwater level is at the ground surface.
- Wet unit weight is 130 pcf.
- Submerged unit weight is 65 pcf.

Calculation Procedure: From the formulas provided in Figure 5.2 lateral pressures are computed as follows:

$\mathbf{P_1}$ = 0.3 x 65 pcf x 20-ft = 390 psf (Figure 5.1)

$\mathbf{P_w}$ = 62.4 pcf x 20-ft = 1,248 psf

$\mathbf{P_q}$ = 500psf x 0.5 = 250 psf

Horizontal pressure at the ground surface = $\mathbf{P_q}$ = 250 psf

Lateral pressure at depths of H/4 (5-ft) = $\mathbf{P_1} + \mathbf{P_w} + \mathbf{P_q}$ = 488+62.4x5+250 = 1,050 psf

Lateral pressure at depth of 20-ft = $P_1 + \mathbf{P_q} + \mathbf{P_w}$ = 390+250+1248= 1,888 psf

APPENDIX D
(cont'd)

Design Example 3

Given: Determine the bracing pressures by using the formulas provided in Figure 5.3 assuming the following:

- Assume depth of 20 ft.
- Cohesive soils are encountered from ground surface to a depth of 12 ft underlain by cohesionless soil to the excavation depth of 20 ft.
- Assume a surcharge load at the ground surface (q) of 500 psf.
- Assume groundwater level is at the ground surface.
- Submerged unit weight is 64 pcf (clay).
- Submerged unit weight is 41 pcf (sand).

Calculation Procedure: From the formulas provided in Figure 5.3 lateral pressure is computed as follows:

$$\mathbf{P_1} = 0.3 \text{x} \left[\frac{64(12) + 41(20-12)}{20} \right] \text{x}\, 20 = 329\,\text{psf}$$

$\mathbf{P_w}$ = 62.4 pcf x 20-ft = 1,248 psf

$\mathbf{P_q}$ = 500 psf x 0.5 = 250 psf

Horizontal pressure at the ground surface = $\mathbf{P_q}$ = 250 psf

Lateral pressure at depth of H/4 (5-ft) = $\mathbf{P_1} + \mathbf{P_w} + \mathbf{P_q}$ = 329+5x62.4+250 = 891 psf

Lateral pressure at depth of 20-ft = $\mathbf{P_1} + \mathbf{P_w} + \mathbf{P_q}$ = 329+62.4x20+250 = 1,827 psf